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NBC Hazard Prediction Model Capability Analysis

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PREFACE

This document was prepared by the Institute for Defense Analyses (IDA) for the Deputy Assistant to the Secretary of Defense, Nuclear and Chemical and Biological Defense Programs (Counterproliferation and Chemical /Biological Defense), in partial response to the task "NBC Hazard Prediction Model Capability Analysis." The primary objective of this task was to determine whether the standard DoD hazard prediction models produce similar results in common scenarios. This document is the final report of the analysis effort.

The IDA Technical Review Committee was chaired by Mr. Thomas P. Christie and consisted of Mr. Rosser Bobbitt, Dr. Nathan Platt, Mr. Douglas P. Schultz, and Dr. William J. Sheleski.

We thank LTC(P) Stan Lillie and Dr. Peter B. Merkle, both from DATSD NCB (CP/CBD); model proponents/developers associated with the Defense Threat Reduction Agency (formerly Defense Special Weapons Agency) and from the Naval Surface Warfare Center, Dahlgren Division; and Professor Steve Hanna (George Mason University) for their comments and insights throughout this study.

NBC HAZARD PREDICTION MODEL CAPABILITY ANALYSIS

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SUMMARY

A. BACKGROUND AND METHODOLOGY

The Department of Defense has three NBC hazard prediction models that have been designated as interim standard: (1) VLSTRACK for hazards from CB weapon attacks; (2) HPAC for hazards from destruction of NBC facilities; and (3) D2PCw for industrial chemical hazards from accidents or incidents. Because of concern about variance in hazard predictions produced by operational users, IDA was asked to conduct a limited operational assessment of the models.

The initial step in the study approach was to gain an understanding of how operational users employ the models and get information concerning their needs, priorities, and any constraints due to time, training, equipment, or other factors.

Simultaneously, we obtained the models and installed them at IDA. We exercised the models, starting with simple cases, and looked for variances in output. When differences in results were found, we attempted to identify the likely source. Other tasks included determining the feasibility of using the models with high-resolution weather data, and identifying field trial data that might be applicable for comparing to model predictions. Actual comparisons to field trial data were deferred to some future effort.

In developing scenarios and exercising the models, the sponsor's guidance was to focus on how operational users would employ the models. As the study progressed, the scope was further refined to concentrate on VLSTRACK and HPAC, since these were the only models that could properly be compared in CB weapon attack scenarios.

B. RESULTS

1. Model Employment by Operational Users

We conducted an informal survey of the primary NBC officers at the CINCs and many of the major commands. We visited the Joint Staff, SOCOM, III Corps, 4th Infantry Division, XVIII Airborne Corps, and the 82nd Airborne Division. We surveyed other commands by telephone.

We did not find many operational users of these models. Most of the users identified were at strategic and operational levels, such as DIA, STRATCOM, SOCOM, and USFK. The principal model employed was HPAC. At the tactical level, we found a very strong interest in the possible use of these models to support both planning for and responding to CB events, but there was little evidence of their being used.

We found that there are significant differences in the conditions that exist at the various operational levels. The

differences in focus, opportunities for model use, skills and background of available personnel, and ability to maintain adequate skills are likely to have a considerable impact on the employment of the models and the value derived from their use.

There was little evidence, at any of the levels surveyed, of standardization or institutionalization of CB hazard prediction in general, or the use of models such as HPAC or VLSTRACK in particular.[1] There was an almost universal call for better model training programs, which would address not only the needs of model operators, but also those of the ultimate customer.

2. Variation Between Models

We found that, even in relatively simple comparable scenarios, the two models could sometimes produce very different predictions. For example, when using default inputs, the predicted area sizes of the lethal concentration for 2 percent of the exposed population ("LCt2") for the release of biological warfare agent A (BWA)[2] (500 Kg dispersed by a sprayer) varied by factors, typically, greater than 10 (with the HPAC prediction being larger). Differences in predictions for chemical weapon agent releases were also found. For instance, the area sizes predicted for the lethal dosage (via skin contact/deposition) for 2 percent of the exposed population ("LD2") for the release of VX from a ballistic missile differed substantially (with the VLSTRACK prediction, in general, being larger).

We found that in several cases there were significant differences in source term and toxicological assumptions. These differences could, in some cases, be exacerbated by variations in the menus, displays, outputs, and ways in which the users provide input.

By overriding the default assumptions of one model or the other, we were able to create similar "input" conditions for both models. **We ran the models with these similar settings and were able in some (but not all) cases to reduce the differences in the results observed.** For example, for the release of biological warfare agent B (BWB) from a ballistic missile, we found that the predicted LCt2 area sizes differed between models by a factor of 7 when the default settings (assumptions) were used. However, this difference was reduced to within a factor of 2 when the similar settings were used. Similarly, the release of VX from a ballistic missile at 1,000 m led to predicted LD2 area sizes that differed by factors up to 12. These differences were reduced to within a factor of 2 by incorporating similar, albeit not default, settings.

The differences between model predictions appeared to be most significant when longer-range, lower-level concentrations were considered. These longer-range, lower-level scenarios are typically consistent with biological warfare agent releases. For instance, releases of the highly lethal BWA led to differences in the presented area sizes at LCt2 of factors

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1 The tactical units surveyed use some form of NATO ATP-45 to support <u>initial</u> warnings of potential hazards. This process is well understood, but the units visited felt that it was too conservative for subsequent decision making. Tactical users felt that a model that would allow them to reduce the uncertainty associated with the ATP-45 process could potentially contribute significantly to CB defense.

2 In order to maintain an unclassified document status, BWA, BWB, and BWC are codes that we use throughout this document to represent three relatively common potential biological warfare agents.

between 4 and 37, even after accounting for the input and toxicological assumptions.

Our analyses suggest that a significant portion of the variance in model predictions is due to fundamental differences in the modeling of transport and dispersion – in particular, different approaches for the incorporation and communication of uncertainty. By removing some of the HPAC uncertainty features – not a developer-recommended mode for predictive operational usage – we were able to show that, in some cases, the differences between model predictions could be further reduced. For instance, the HPAC-predicted LCt2 mean area sizes for releases of BWB from a sprayer (with the similar settings employed) were larger than the corresponding VLSTRACK-predicted areas by factors between 6 and 10. By eliminating some of the HPAC uncertainty features, namely the incorporation of large-scale variance and the meandering component of turbulence, the model predictions could be brought to within a factor of 1.7, for these BWB scenarios. For clarity, we must emphasize that we do not expect operational users, particularly at the tactical level, to have the available expertise to knowledgeably eliminate HPAC uncertainty features nor would they necessarily want to do this when employing the model in the predictive mode.

Our analyses have also suggested that there are other differences in the modeling of hazard transport between the models. For instance, we found that the center of the "concentration cloud" traveled substantially further for the HPAC predictions than for the VLSTRACK predictions. We also noted differences in the modeling of vapor (or small droplet) deposition, secondary evaporation, and higher altitude source term assumptions.

C. CONCLUSIONS AND RECOMMENDATIONS

In light of the fundamental differences seen in this study, variance in the models' outputs for the same tactical situations should not be surprising.

Steps to improve the value of CB hazard predictions should include standardizing the model descriptions of sources, and the model assumptions about lethality effects. Hazard prediction and its employment should be institutionalized – doctrine and procedures should be developed and taught at the schools and commands.

Validation of hazard prediction models should be conducted by an independent agency. If it is desired to compare validation results between models, then similar methodologies, which must include an uncertainty analysis, should be employed for the model/field trial data comparisons.

Improving the contribution of these models to CB defense will require continued emphasis on matching the model features (e.g., required inputs, outputs, connectivity) to the capabilities and limitations of the prospective operational users. This "matching of operational needs" is likely to be most important for users at the tactical level.

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NBC Hazard Prediction Model Capability Analysis

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INTRODUCTION

In November 1996, acting under combined Congressional mandates, the ATSD(NCB/CBM) and the DUSA(OR) jointly designated three models as DoD Interim Standard NBC Hazard Prediction Models: (1) VLSTRACK for hazards from CB weapon attacks; (2) HPAC for hazards from destruction of NBC facilities; and (3) D2PCw for industrial chemical hazards from accidents or incidents. Because of continued technology developments and the concern that in some instances the models were producing different results for the same scenarios, the DATSD NCB (CP/CBD) asked IDA to conduct a limited operational assessment of the models. The primary objective was to determine whether the hazard prediction models produced similar results when used in common scenarios.

Fundamental to the study approach was to gain an understanding of how operational users employed the models. We obtained from the model proponents the current versions of the models and installed them at IDA. We exercised the models, starting with simple cases, and looked for variances among model outputs. When differences in results were found, we attempted to identify the likely source. Other tasks included determining the feasibility of using the models with high-resolution weather data, and identifying field trial data that might be applicable for comparing to model predictions.

In developing scenarios and exercising the models, the sponsor's guidance was to focus on how operational users would employ the models. The study's scope did not include assessing the technical approaches used by the models or validating their mathematical underpinnings. Technical reviews of both SCIPUFF – the transport and dispersion code associated with HPAC – and VLSTRACK have recently been published.[3]

As the study progressed, the scope was further refined to concentrate on VLSTRACK and HPAC, since these were the only models that could properly be compared in CB weapon attack scenarios.[4]

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3 *Technical Review of the VLSTRACK Dispersion Model*, Air Resources Laboratory, NOAA, November 1996, and *Second Order Closure Integrated Puff (SCIPUFF) Model Verification and Evaluation Study*, Air Resources Laboratory, NOAA, May 1998. Based on the NOAA review, the VLSTRACK developers have made some changes to their code and their validation methodology with work continuing.

4 The D2PCw model is tailored to the specific needs of its user, the Chemical Stockpile Emergency Preparedness Project Manager, whose concern is potential accidental releases of chemical agent, from either the nine chemical weapon stockpile sites or the on-site agent destruction facilities. Thus, detailed source terms, default weather, and site map information are provided for only the nine sites of concern. Considerable additional development of model input information, which was beyond the scope of our study, would be required for this model to have a wider applicability.

Introduction

- **Issue: concern about variance in NBC hazard predictions produced by operational users**
- **Study approach**
  - Understand how operational users employ the models
  - Obtain models
  - Exercise models
    - » Replicate user environment
    - » Start with simple cases, move to complex
    - » Look for variances in outputs
  - Identify likely sources of variance: technical/operational
  - Other tasks
    - » Demonstrate interface with complex weather data
    - » Identify field trial data for validation (comparison deferred to future efforts)
- **Scope**
  - Operational evaluation, not technical review
  - Primary focus on HPAC and VLSTRACK

STUDY METHODOLOGY PART I: SURVEY OPERATIONAL USERS

In keeping with the operational focus of the study, input was needed from typical operational users concerning the needs, priorities, and decisions to be supported by NBC hazard prediction information. In order to develop the scenarios to exercise the models, we also wanted to identify the types of information typically available to be used as inputs to the models, and any operational constraints due to time, training, equipment, or other factors.

First we identified three categories of users of hazard prediction models. "Researchers" are those users who are primarily responsible for developing the models and the technology upon which the models are based. The "Studies" community includes those users who employ the models in support of NBC-related studies, e.g., weapons systems analyses, and force structure studies. "Operational" users are those who use the models in support of operational planning and real-time decision making. Since the study was focused on "operational" users, and to facilitate discussions concerning that category, it was further defined to include users at the "strategic," "operational," and "tactical" levels of command.

Study Methodology Part I: Survey of Operational Users

- **Focus of study on operational users**
- **Needed to understand better the operating environment of a typical operational user**
  - Development of scenarios to be used in running models
  - Information typically available to be used as inputs
  - Other constraints, e.g., time, space, computing capability, training, personnel
- **Segmented users into several categories**
  - Research
  - Studies
  - Operational
- **Assigned operational users to one of several levels of command to facilitate discussions of operating environments and needs**
  - Strategic (national, Joint Staff, DIA, CIA)
  - Operational (major combatant command, CINC, JTF)
  - Tactical (Corps and below, ships, airbases)

STUDY METHODOLOGY PART I: SURVEY OPERATIONAL USERS (cont'd)

We conducted an informal survey of the primary NBC officers at the major commands listed on this chart. We visited the Joint Staff, SOCOM, U.S. Forces Korea, III Corps, the 4th Infantry Division, XVIII Airborne Corps, and the 82nd Airborne Division. We surveyed the other commands by telephone. Several unsuccessful attempts were made to identify potential Air Force and Navy users at the tactical level.

We made no attempt to conduct a rigorous statistical sampling of all operational users. Rather, the objectives of our informal survey were to determine if, and how, the models were being used, and to learn about the operating environments and factors that might influence model use and utility.

Study Methodology Part I: Survey Operational Users (cont'd)

- **Conducted an informal survey (either by personal visit or by phone) of primary NBC officers at major commands**
  - Joint Staff *
  - EUCOM
  - CENTCOM
  - PACOM
  - STRATCOM
  - SOCOM/USASOC *
  - ACOM
  - LANTFLT
  - USFK/EUSA *
  - I Corps
  - III Corps *
  - 4th Inf Division *
  - V Corps
  - XVIII Airborne Corps*
  - 82nd Airborne Division *
- **Objectives**
  - Determined whether models were being used, and if so, how
  - Discussed operating environments
  - Identified user priorities and needs for CB hazard prediction
  - Not a rigorous headcount of users

* Personal visits

USER OBSERVATIONS: DISTRIBUTION OF MODEL USERS

The principal observations developed during our user survey are summarized in the following charts. A somewhat more detailed discussion is provided in Appendix A.

First, we were not able to identify very many operational users of either HPAC or VLSTRACK. Prior to the start of our survey, we were given the impression that the two models, HPAC and VLSTRACK, were in common use among operational users, and that impression was certainly reinforced by the lists of users initially provided by the two model groups. Most of those users identified during our survey were located at the strategic and operational levels. Included in these categories are the DIA, STRATCOM, USFK, and SOCOM. Copies of the models existed at several of the other major combatant commands, such as EUCOM and PACOM, but the models were not being used by those commands. At the tactical level, we found a very strong interest in the possible use of these models to support both planning for and response to CB events, but there was very little evidence of their being used. Among the tactical units surveyed, only the 82nd Airborne Division indicated any real experience with either model.

The tactical units surveyed did use some form of NATO ATP-45, or an equivalent technique, to develop predictions to support initial warnings of potential hazards. None of these units were completely satisfied with this approach, however. For while such a technique is timely, the units said it is too conservative to support subsequent decision-making. They felt that a model that would allow them to reduce the uncertainty associated with the ATP-45 process could contribute significantly to CB defense. Ultimately, improving the accuracy of CB hazard predictions will require any model to incorporate near real-time measured/forecasted weather and probably, near real-time observed chemical/biological agent concentration information (e.g., survey data).

User Observations: Distribution of Model Users

- **We did not identify many <u>operational</u> users of either HPAC or VLSTRACK**
- **Most of the operational users were at the strategic and operational levels**
  - DIA
  - Some CINCs (STRATCOM, CENTCOM, USFK, SOCOM)
- **Strong interest in models encountered at tactical levels, but very limited use to date**
  - NATO ATP-45 or equivalent used for initial warnings

USER OBSERVATIONS: MODEL USAGE

In virtually every case where an operational user was interviewed, regardless of level, the model of choice was HPAC. In a few instances, VLSTRACK was used as a backup when questions were raised concerning the HPAC predictions.

Invariably, the basis for model choice involved "added capabilities provided," such as the ability to portray terrain and infrastructure easily; relatively straightforward access to near real-time weather data; access, via the HPAC CD, to historical weather; and the capability to model the destruction of chemical/biological weapons facilities and nuclear and radiological weapons.[5] No user surveyed was able to talk knowledgeably about the relative accuracies of the two models, and few had any idea how accurately such models might predict reality.

One phenomenon that we encountered during our search for operational users was that the use of models was often dependent on the personalities involved. For example, we might be told that a particular officer at a headquarters was a frequent user of a given model. But when we tried to contact the individual, we might find that he had recently transferred and that the models were no longer being used at that location. Likewise, we found locations where the models had not traditionally been in use until a particular individual had been assigned to the organization.

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5 We verified the relative ease of access to near real-time data by doing a few HPAC predictions that included recent observations that were posted on a University of North Carolina – Charlotte web site (http://ws321.uncc.edu/data/). These observations, upper air and surface, were downloaded and used to create, via the HPAC weather reader and weather editor, a weather input file. The whole process, to include accessing the web site, downloading via the internet, and printing the "dual run, terrain included" trial took (us) under 30 minutes.

User Observations: Model Usage

- **Among the users at the strategic and operational levels that employed the models**
  - HPAC was the clear model of choice
  - VLSTRACK was used, in a few instances, in a back-up mode
- **Basis for preference appeared to be the availability of specific capabilities, such as the ability to portray terrain and infrastructure, model weapon facilities, and relative ease of access to weather data (near real-time and historical)**
- **Use of models at operational levels frequently dependent on personalities (EUCOM, PACOM, USFK, 82nd ABD)**

USER OBSERVATIONS: OPERATING ENVIRONMENTS

We found that there are significant differences in the conditions that exist at the various levels, and that these differences are likely to have a considerable impact on the employment of the models and the value derived from their use. For example:

- At the strategic and operational levels the models are used primarily to support operational planning, whereas at the tactical level we envision (based on discussions with potential users) that the primary focus will be on real-time predictions of hazards due to CB attacks launched by enemy forces. This difference in focus has a significant impact on the response times required, as well as the nature and source of inputs used.
- The opportunities to employ the models, and hence maintain adequate familiarity, also are likely to vary significantly between the strategic/operational and the tactical levels. In the case of the former, it was not unusual to find that the models were used almost daily. Whereas at the tactical level, it was envisioned that opportunities, governed primarily by the frequency of major training exercises, would be few and far between.
- The skills and backgrounds of available personnel assigned to the various levels also varied considerably. At the strategic/operational levels, it is more likely that readily available personnel will have the specific skills that are needed to employ these models effectively, e.g., specialists in meteorology (MET). At the tactical level, however, there was considerable concern about their ability to acquire and retain personnel with sufficient backgrounds to operate the models and properly interpret their results.
- The ability of the strategic/operational user to maintain adequate skills is significantly better than that of users at the tactical level. This is a direct result of several factors: differences in opportunities to employ the models, turnover of personnel, and availability of adequate training programs.
- Several of the users at the strategic/operational levels have access to contractor personnel to operate the models. This seemed to alleviate many of the personnel problems previously mentioned. It is not envisioned that such a capability would exist at the tactical level.

User Observations: Operating Environments

- **There are significant differences in the operating environments of potential users at the various levels involving**
  - Focus of effort
  - Opportunities to use models
  - Skills and backgrounds of available personnel
  - Ability to maintain adequate skills
  - Access to contractor support

USER OBSERVATIONS: PROCESSES AND PROCEDURES

We found little evidence, at any of the levels surveyed, of standardization, or institutionalization, of CB hazard prediction in general, or the use of models such as HPAC or VLSTRACK, in particular. Clearly the use of models, such as HPAC or VLSTRACK, at the strategic and operational levels provides some degree of standardization. But our discussions with users at these levels did not indicate that there was any unifying doctrine, or procedures, concerning the use of models for hazard predictions.[6]

There was an almost universal call for better model training programs that would address not only the needs of model operators, but also those of the ultimate customer. Current training programs were criticized for not providing sufficient depth. It was emphasized that future programs should be capable of being conducted frequently and locally.

Operational users at all three levels expressed a strong interest in assessing toxicity levels well below what they considered "militarily significant." The basis for concern about these lower levels of toxicity was related to legal and moral issues and the need to address peacetime incidents or accidents.

The need to improve the portrayal of CB events during training events was brought up several times, particularly at the tactical level.

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6 The tactical units surveyed use some form of NATO ATP-45 to support initial warnings of potential hazards. This process is well understood, but the units visited felt that it was too conservative for subsequent decision making. Tactical users felt that a model that would allow them to reduce the uncertainty associated with the ATP-45 process could potentially contribute significantly to CB defense.

User Observations: Processes and Procedures

- **Little evidence of standardization, or institutionalization, of**
  - Use of models
  - Use of model outputs
- **Need for better training programs**
  - For model operators
  - For end-users of model outputs
  - That can be conducted frequently and locally
- **Operational users interested in assessing toxicity levels well below what is considered "militarily significant"**
  - Legal
  - Moral
  - Peacetime incidents
- **Need to improve portrayal of CB activities during major training events**

STUDY METHODOLOGY PART II: EXERCISE MODELS

As a part of this study, we exercised the VLSTRACK 1.6.3 and HPAC 3.1 models. The goal of this effort was to obtain insight into the usage of these models and to develop a basic understanding of the types of differences in predicted hazards that might be expected between the two models. We compared model inputs (including defaults) and outputs (predictions) over a variety of scenarios. With respect to chemical weapons, we considered GD (Soman) dispensed by an aerial sprayer, GB (Sarin) delivered by 152mm artillery, and VX (and thickened VX) released from a ballistic missile. We also examined biological weapons scenarios that included the dispersal of biological warfare agents A (BWA), B (BWB), and C (BWC) via an aerial sprayer and a ballistic missile with submunitions.

For each scenario, we prepared comparisons between models of chemical and biological agent dosage and concentration and of chemical agent surface deposition. First, we used the input default settings whenever possible, since we felt that was most consistent with the capabilities of users at the operational and tactical levels. Then, where observable (and significant) differences in predictions and/or inputs existed, and they always did, we reran the trial, using settings that were made to be as identical as possible (at least as similar as we could). These "similar" settings trials allow us to diagnose, at least to a degree, the cause of the observed differences.

Our comparisons were limited to chemical and biological weapons releases only – that is, facilities that may contain weapons were not examined. The operational user that we envisioned had a limited amount of time (on the order of an hour or two) and information with which to complete his prediction.[7]

For some of the scenarios that we examined, we investigated the impact of some of the fundamental parameters associated with each model (e.g., conditional averaging and long-term variability for HPAC). The goal of these analyses was to provide support to the hypothesis that observed differences in predictions between the models were, in some cases, due to fundamental differences in the modeling of transport and dispersion and, in particular, different philosophies for the incorporation of uncertainty into the prediction.[8]

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7 Some scenarios might require decisions to be made within a few minutes. For such applications, it seemed to us that precalculated conservative areas of the hazard, perhaps with automated messaging and communications, would be necessary. We did not consider this "quick response" scenario. Likewise, we did not examine the usage of these models as research and development tools, where there may be lots of time for parametric study (days or weeks) and the weather and source terms are "known," theoretically, in great detail.

8 It was recognized early on that uncertainty in source term characteristics and forecasted weather could, for many applications, limit any model's predictive capability.

Study Methodology Part II: Exercise Models

- **Compare predictions of models**
  - Examine from an operational user's perspective
  - 5 Scenarios
    - » 3 chemical weapon release types (sprayer, artillery, and missile)
    - » 2 biological weapon release types (sprayer and missile with submunitions)
  - Model Runs
    - » Use "default" settings (most likely mode of tactical users)
    - » Rerun using "similar" settings
    - » Rerun to isolate key fundamental factors

- **Limit comparisons**
  - Compare VLSTRACK 1.6.3 to HPAC 3.1 (both run on PC)
  - Compare only chemical and biological weapons
    - » No chemical/biological facilities

- **Look for fundamental differences in output**
  - Differences due to incorporation of uncertainty
    - » Displayed information (communication of hazard area)
  - Differences due to transport and dispersion modeling

OBSERVATIONS FROM CHEMICAL WEAPON RELEASE COMPARISONS

When the default settings were used, the models reported significantly different areas of hazard for several of the weapon releases that we examined. With respect to the areas associated with surface deposition (at "LD2") for the GD sprayer release trial HPAC typically presented areas that were a factor of two or more larger than the reported VLSTRACK area size.[9] Our comparisons of the release of VX and thickened VX from a ballistic missile (at an altitude of 300 and 1,000 m) led to presented surface deposition area sizes (at "LD2") that differed by factors of between 3.8 and 7.5. For the artillery scenario that we investigated, the predictions of hazard areas, both from inhalation (dosage, LCtX) and skin contact (surface deposition, LDX) were similar.

Several differences in default settings were noted. For example, the models assumed different mass median droplet diameters (MMD) for what appeared to be similar scenarios (e.g., the release of VX or thickened VX via a missile). Similarly, HPAC assumed lethal (vapor inhalation) concentrations for 50 percent of an exposed population (LCt50) of 70, 70, and 30 mg-min/m^3, for GD, GB, and VX, respectively. VLSTRACK employed LCt50 values of 35, 35, 15, respectively.[10]

Rerunning the chemical weapon release trials with the input settings set as similarly as possible, typically by overriding default parameters in one model or the other, led to some improvements in agreement between models. This requires a level of expertise, at least for some of these parameters, which will not likely be available at the operational and tactical levels. In particular, fixing the MMD values for the VX/thickened VX ballistic missile release led to much more similar LD2 surface deposition area sizes.[11]

In all cases, there were large differences in the displayed area sizes associated with the lower level concentrations that were reported. Our analysis suggests that some of these differences are due to fundamental differences in the modeling of transport and dispersion and, in particular, to philosophical differences in the incorporation and presentation of uncertainty.

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9 Early in our study, we identified a software bug in VLSTRACK, at least in the way in which we were implementing it on a Windows-based personal computer, that caused the displayed areas to be smaller than the actual VLSTRACK prediction. This problem was confirmed with the developer, and, throughout the following discussions, only the correct reported VLSTRACK area sizes are used.

10 Other differences noted during our chemical release comparisons included the assumed mass per 152mm artillery round, the dissemination efficiency, and the default wind measurement height for a simple fixed wind trial.

11 Additional information can be found on page B-65.

Observations from Chemical Weapon Release Comparisons

- **In two of the three scenarios that we examined, the HPAC and VLSTRACK predictions of areas of hazard differed significantly**
- **Default setting assumptions can be different in important ways**
  - For example, default assumptions associated with agent mass per round, dissemination efficiency, mass median droplet diameter, and lethality levels were found to differ significantly between models
  - Using "similar" settings can greatly reduce, but not eliminate, differences between the models' predictions of hazard areas
- **Reported areas of low-level concentration were quite different**
  - Differences in the modeling of transport and dispersion
  - Differences in the incorporation of uncertainty and the communication of the prediction

OBSERVATIONS FROM BIOLOGICAL WARFARE AGENT RELEASE COMPARISONS

Two biological warfare agent release scenarios were examined – the release via a sprayer and the dispersal from 50 exploding submunitions delivered by a ballistic missile.

The models predicted very different areas of hazard when the default settings were used to examine biological warfare agent releases. In general, the predicted LCt2 area sizes differed by factors of 5 to 1,000 between models.

Much of this large difference was due to differences in assumptions embedded in the models. By overriding these default assumptions and using similar settings for each model, differences between the model predictions could be greatly reduced. The most significant default assumption differences that we observed during our examination of biological warfare agent releases were:

- Effects/lethality assumptions (and probably definitions) for BWB and BWC
- Agent mass released per round (purity and dissemination efficiency)
- Biological agent daytime and nighttime decay rate.

Rerunning the bio-agent release scenarios with similar settings led to differences in LCt2 area size predictions that were, with one exception, less than a factor of 15 and, in general, less than a factor of 10.

In a few of the cases involving the less lethal agents – BWB and BWC – differences between the models were reduced to within a factor of 2 by using the similar settings. In other cases, differences of less than a factor of 2 were obtained for BWB and BWC by eliminating fundamental HPAC uncertainty features – large-scale variance and conditional averaging.

Both models assumed that BWA was highly lethal – about 5 orders of magnitude by mass more lethal than BWB or BWC. Therefore, much less material was required to generate a given BWA hazard area (relative to the other agents). For these BWA trials, in which much smaller amounts of material are significant, the predictions of the models, even after adjusting the input parameters (i.e., using similar settings), typically differed by factors of between 4 and 15, and in one case, the HPAC presented area size at LCt2 was a factor of 37 larger than the reported VLSTRACK area size.

Observations from Biological Warfare Agent Release Comparisons

- **The HPAC and VLSTRACK predictions of areas of hazard differed significantly**
  - Predicted area sizes of hazardous exposure differed by factors between about 5 and 1,000
- **Default setting assumptions can be different in important ways**
  - Default assumptions associated with agent purity, dissemination efficiency, agent decay rate, and lethality levels were found to differ significantly between models
  - Using "similar" settings can greatly reduce, but not eliminate, differences between the models' predictions of hazard areas
- **Turning "off" fundamental HPAC uncertainty features led to reduced differences between some model predictions**

STANDARDIZING INPUT ASSUMPTIONS CAN GREATLY REDUCE DIFFERENCES BETWEEN THE MODEL PREDICTIONS

We did not do an exhaustive comparison of model predictions. However, a recurring theme of our limited observations, for both the chemical and biological warfare agent releases, was the substantial difference in "input" assumptions between the two models. Based on our survey, while users at the strategic level may be aware of the potential importance of these assumptions, we question that such will be the case at the operational level, and are fairly certain it will not be true at the tactical level. **It seems likely that operators at different locations, one using VLSTRACK and one using HPAC, could easily arrive at very different predictions and, hence, different militarily significant decisions.**[12]

Assuming that it is important to reduce the differences in predictions between these two models, an important first step would be to standardize, where possible, the definitions and values of many of the input parameters.

With respect to chemical weapon source terms, we found that significant differences, for instance, in assumed dissemination efficiency and mass median droplet diameter, existed between models.[13] For example, by using similar settings for the lower altitude (< 1,000 m) release of VX or thickened VX from a ballistic missile, differences in the presented surface deposition areas (at "LD2") were reduced from factors of between 3.8 and 7.5 to between 1.1 and 2.7.

Similar conclusions were reached for the release of biological weapons. **In the case of biological warfare agent source terms, the biggest differences in assumptions between models were associated with the assumed viable mass.** Differences in assumed purity, dissemination efficiency, mass per submunition, and agent decay rate were deemed significant. Whereas VLSTRACK assumed that only a fraction (between 2 and 90 for the cases examined) of the released material represented viable agent, the HPAC defaults appeared to assume that all of the released agent was viable. Again, we question whether a typical operator of these models would recognize this difference.

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12 We also expect that differences in model predictions will result from the use of different weather inputs, even assuming the same source term. In fact, given differences in the available weather data and source term input choices that a user might make, it is not unreasonable to expect that at two different locations, even when using the same model, significantly different predictions might arise.

13 Other differences associated with the characterization of the source term (e.g., mass per 152mm artillery round, initial size, and lateral sigma) and initial weather input (assumed wind measurement height for simple winds) were also observed and probably could be standardized.

Standardizing Input Assumptions Can Greatly Reduce Differences Between Model Predictions

- **Chemical weapons source terms**
  - Dissemination efficiency, mass median droplet diameter, mass per artillery round
    - » Initial size, lateral sigma, assumed burst height, assumed wind measurement height, droplet distribution sigma, line source length, fall angle, number of rounds per artillery barrage
- **Biological weapons source terms**
  - Purity, agent decay rate, dissemination efficiency, mass per submunition
    - » Initial size, lateral sigma, assumed burst height, assumed wind measurement height, droplet distribution sigma

STANDARDIZING LETHALITY/EFFECTS ASSUMPTIONS CAN GREATLY REDUCE DIFFERENCES BETWEEN THE MODEL PREDICTIONS

We found that the two models, in general, assumed different dosages, for a given level of lethality. In the biological warfare agent cases of BWB and BWC, the assumed levels for the same lethality differed by factors of about 3 and 65, respectively. We suspect that in some cases the model developers may have interpreted or defined lethality or agent effectiveness in different ways – for example, HPAC often reports incapacitation levels for some agents. For chemical agents, assumed LCt50 levels were found, in some cases, to differ by a factor of 2.[14]

VLSTRACK does not directly compute skin contact hazard because of the wide range in type of clothing and amount of exposed skin that would need to be considered. On the other hand, HPAC reports a skin contact hazard with the assumption of 1 m^2 of exposed skin. Standardizing the effects assumptions associated with skin contact will require some assumed model of exposed skin area.

Standardization of assumed lethality levels and the consistent identification and definition of reported effects could greatly reduce the differences in the reported and perceived differences in predictions between models. **There is a need for a disciplined process to ensure that the chemical and biological agent toxicity assumptions that reside within the models are consistent and appropriately updated as new clinical reviews become available.**

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14 The LCt50 values assumed by VLSTRACK for GB, GD, and VX appear to have their origin in a 1994 review paper. See *Review of the Existing Toxicity Data and Human Estimates for Selected Chemical Agents and Recommended Human Toxicity Estimates Appropriate for Defending the Soldier*, S. A. Reutter and J. V. Wade, Edgewood Research, Development and Engineering Center, U.S. Army Chemical and Biological Defense Command (ERDEC-SP-018), March 1994. HPAC appears to assume the existing standards as of 1994. That is, HPAC did not adopt the recommendations of the 1994 paper. Perhaps these recommendations were not officially, in some sense, approved.

Standardizing Lethality/Effects Assumptions Can Greatly Reduce Differences Between Model Predictions

- **Definitions**
  - Lethal versus incapacitating versus threshold
- **Skin contact hazards**
  - Assumed exposed skin area
- **Inhalation hazards**
  - GD, GB, VX, BWB, and BWC
- **Disciplined process to review and update**
  - Toxicological reviews

FUNDAMENTAL DIFFERENCES IN THE MODELING OF TRANSPORT AND DISPERSION CAN LEAD TO SUBSTANTIAL DIFFERENCES IN PREDICTIONS

HPAC uses a transport and dispersion (T&D) model called SCIPUFF and an associated mean wind field model. SCIPUFF is a model for atmospheric dispersion that uses the Gaussian puff method – an arbitrary time-dependent concentration field is represented by three-dimensional Gaussians – and bases the turbulent diffusion parameterization on second-order closure theories that provide a connection between measurable velocity statistics and the predicted dispersion rates.[15]

VLSTRACK also uses a Gaussian puff method with many of the calculations coming directly from the Non-Uniform Simple Surface Evaporation (NUSSE4) model developed by the U.S. Army. VLSTRACK uses the inverse Monin-Obukhov length (Γ) to calculate cloud dispersion parameters.[16] Given an estimate of the Pasquill stability category, Γ can be computed by VLSTRACK via an equation. The Pasquill stability category is determined using previously established nomograms.

Our analyses suggest that by overriding model default values and eliminating one of the HPAC uncertainty features – setting the conditional averaging time (T_{avg}) to zero and, hence, removing the meandering component of the modeled turbulence – HPAC and VLSTRACK results can be made more similar. For example, setting HPAC $T_{avg} = 0$ led to surface deposition area size predictions (GD sprayer release at 7 mg/m^2) that were more consistent with the nominal VLSTRACK predictions.

Similarly, eliminating the large-scale wind variability feature of HPAC and setting $T_{avg} = 0$ led to predicted LCt2 area sizes that were within a factor of 2 between HPAC (mean area) and VLSTRACK for BWB and BWC (down from factors of between 4 and 10 for the nominal "similar" settings cases). For two simple curved wind cases, a similar result was obtained for BWA when released from a ballistic missile with 50 submunitions (down to within a factor of about 2 from a factor of about 4).

The above analyses support the contention that differences associated with the incorporation of uncertainty can lead to substantial differences between reported model predictions. However, for the simple fixed wind BWA release from a sprayer, the elimination of large-scale variability and setting of T_{avg} to 0 did not substantially reduce the differences (factors of about 4 to 6) in the predicted LCt2 area sizes between models.

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[15] The "second-order" feature implies that concentration fluctuation variance can also predicted. See *Verification and Validation of HPAC 3.0*, Logicon R and D Associates for DSWA, June 1998, page C-7.

[16] Γ is a meteorological parameter associated with thermal stratification and the representation of the magnitude of buoyancy forces which can enhance or diminish turbulence and mixing.

Fundamental Differences in the Modeling of T&D Can Lead to Substantial Differences in Predictions

- **Fundamental Model Features**
  - HPAC – Gaussian puff, second-order closure technique and assumed clipped Normal distribution can allow for computation of probabilistic features
  - VLSTRACK – Gaussian puff based on NUSSE4 .
- **Uncertainty Features**
  - HPAC
    - » Full-spectrum of turbulence considered (e.g., meandering component of turbulence)
    - » Large-scale variance (mesoscale variability)
  - VLSTRACK
    - » Monin-Obukhof length, Pasquill stability category to determine cloud dispersion parameters
- **Our analyses suggest that differences in model predictions can be caused by fundamental T&D differences**
  - BWB and BWC release from sprayer
  - Simple curved-wind BWA ballistic missile release

EVIDENCE FOR OTHER DIFFERENCES IN THE MODELING OF HAZARD TRANSPORT

The two models predicted substantially different distances traveled by the cloud center for several of the cases that we examined. For example, for the release of GD from a sprayer, the center of the concentration cloud at 4 hours for the 4, 15, and 30 Kph fixed wind cases, was predicted by HPAC to be at 20, 92, and 192 Km. For the same situation, VLSTRACK predicted cloud center distances of 11, 39, and 88 Km, respectively.[17]

The observed differences in cloud transport downwind suggest that HPAC and VLSTRACK, for this rather simple case, assume different average advection speeds for the center of mass of the cloud. Differing models of the vertical distribution of cloud material between simulations, even for the same assumed wind speed-height profile, could lead to these observed differences in cloud center transport. Alternatively, the wind speed-height profile may be modeled differently for the same single fixed wind observation.

For several of the chemical warfare agent situations that we compared it was obvious that the models predicted different area sizes and shapes for the lower levels of surface deposition. This appears to be related to the fact that VLSTRACK does not consider the deposition of gases or smaller particles/droplets.

Our comparison of the 10,000-m release of thickened VX via a ballistic missile revealed differences in deposition areas (at LD2). While the differences for the three lower altitude releases were greatly mitigated by the use of similar settings, the 10,000-m case remained anomalous. The HPAC-predicted LD2 area was about 5 times larger than the VLSTRACK reported area for this higher altitude case. A few potential causes of this difference seem likely. First, VLSTRACK assumes that a release from a ballistic missile at this height corresponds to a missile "intercept" and as such computes the source term differently (e.g., a different initial vapor-liquid mix). HPAC 3.1 does not make this assumption. In addition, it is feasible that each model characterizes the layer height differently and/or that the transport of the cloud through the layer is modeled differently.

There were some occasions where the VLSTRACK prediction showed evidence of secondary evaporation. The HPAC prediction only showed this secondary evaporation evidence at lower concentration levels – about one or two orders of magnitude lower. The suggestion is that the modeling of secondary evaporation is quite different between models.

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17 These comparative trials were done with similar settings including an assumed wind measurement height of 10 m for the fixed wind.

Evidence For Other Differences in the Modeling of Hazard Transport

- **Distance traveled by cloud center in GD sprayer release**
  - Possible causes
    - » Different assumptions associated with the average advection speed for the cloud center of mass
    - » Differences in modeling of the vertical distribution of the cloud
    - » Differences in modeling of the assumed wind speed-height profile
- **Deposition via vapor (GB artillery and GD sprayer releases)**
- **Deposition area sizes for thickened VX release from a ballistic missile at an altitude of 10,000 m**
  - Possible causes
    - » Different source term characterizations (intercept vs. nominal release)
    - » Different characterization (computation) of the boundary layer
    - » Different modeling of cloud transport through the layer
- **Apparent, but perhaps small, secondary evaporation differences (GD sprayer release)**

MEAN VALUES MAY NOT ALWAYS CORRESPOND TO LIKELY OUTCOMES

Both models purport to present the user with mean values. With respect to predicted area size at a given concentration, dosage, or deposition level, HPAC presents the user with two expected values.

- Area of the Mean Dosage (AMD) – The area in which the mean dosage is greater than some critical value (e.g., LCt50). This value is calculated from the contour based on using the average dosage values at each grid point (dbar{x,y}). This corresponds to the value of the area shown in the graphics display when the user employs the "Mean Value" toggle in HPAC.
- Mean Area – For each realization of the turbulent wind field, a set of dosage values at each grid point (d{x,y}) can be computed. From this dosage field, a dosage area at a specified value can be estimated. The average of these dosage areas, computed in this way over all of the turbulent wind fields considered, is defined here as the mean area. This estimate corresponds to the area reported by HPAC in red as the "Mean Population Exposed" (at a given level or higher) for an assumed density of 1 person per Km^2.

In addition, HPAC's probabilistic feature allows for the prediction of the probability that a given dosage, for instance, is exceeded. Contours can be computed at given probability levels i.e., P(V>E). This area size value is reported in red when the "Probability (V>E)" toggle is used. This value corresponds to the area size contained by the contour in which the population would be exposed to LCtX with risk p_i (e.g., 0.50) or greater.

During the course of our studies, we have noted several instances in which the P(V>E) value is substantially different from the mean area (or AMD) value. For example, for the BWA fixed wind sprayer release, the mean and 0.50 Prob (V>E) values differed greatly. In fact, whereas the HPAC mean area values were 4 to 7 times larger than the reported VLSTRACK area sizes at LCt2, the 0.50 Prob (V>E) area sizes were within a factor of 2.

The relationship between the HPAC predicted mean and 0.50 Prob (V>E) areas is a complicated function of the shape (in two-dimensions) of the distribution from which they arise. Distributions with long "tails" can generate mean values that correspond to very high percentile results (e.g., the 95th percentile or greater). Many operational users, particularly at the tactical level, may not recognize the full scope or implications of this potential difference nor have a good sense for which conditions necessarily lead to long "tails." **We imagine that for many users, the communication of the hazard area via a percentile would have improved operational utility.** For example, presenting hazard contours that represent areas outside of which the probability of a given level of toxicity being achieved is low (e.g., 1 percent) should be useful. The advantage of these "percentile" contours is that they have consistent meaning and, hence, operational utility. For HPAC, this capability seems possible, and may in part, be a motivating factor for the recent incorporation of the "hazard area" feature.

Mean Values May Not Always Correspond to Likely Outcomes

- **Both HPAC and VLSTRACK present the user with mean values (e.g., contours at given levels)**
  - HPAC computes area of the mean dose, mean area at a given dose, and area in which, at a given probability, a dosage level is exceeded – P(V>E)
  - VLSTRACK presents "best estimate" – mean value
- **In some cases, the HPAC mean values can differ greatly from the 0.50 P(V>E) values**
  - Some users may be unaware of the implications of this
- **The utility of hazard area predictions to some users will be improved by using percentile areas as opposed to mean values**
  - It appears that only HPAC can provide such necessarily probabilistic information

FIELD TRIAL DATA SHOULD BE ABLE TO DISTINGUISH BETWEEN MODELS: PART I

The model comparisons that we examined indicated that, even after accounting for differences in inputs and effects assumptions, operationally significant differences in predictions between VLSTRACK 1.6.3 and HPAC 3.1 often remain. It seems natural to expect that field trial data should be able to distinguish between the two model predictions.

Significant effort has been expended in comparing HPAC[18] and VLSTRACK[19] predictions to field trial data for the purpose of model validation. The two model groups have used very different validation methodologies. **If the goal of some future field trial data comparisons is to distinguish between VLSTRACK and HPAC predictions, then similar methodologies should be employed for both model/field trial data comparisons.**

Given the differences in model predictions that we observed, longer-range, lower-level measurements of concentration and dosage, in particular, simulated biological agent releases, might best allow the field trial data to distinguish between the two models. Instantaneous releases appear to best represent most chemical/biological weapon release scenarios and should be considered first. Releases via rockets, mines, ballistic missiles, artillery shells, and most line sources are expected to be of relatively short duration (minute or less).

In addition to a comparison of predicted mean values to observations, any comparison-to-field-trial methodology must include an uncertainty analysis. For instance, confidence intervals associated with model predictions should be described. Any methodology must include comparisons to "downwind," "crosswind," and "upwind" measurements. Measurements along arcs, perhaps averaged over different time periods and with observed variances (as a function of averaging time) would be useful for an uncertainty analysis.

Sensitivity analyses, the goal of which would be to identify those parameters, conditions, and data points that most influenced the results (statistical or otherwise) of the comparison to field trial data, should also be of value. This sort of sensitivity analysis could provide natural insights into the situations that best support a given model's appropriateness – validity.

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18 *Initial Verification and Validation of HPAC 1.3*, Logicon R and D Associates for DSWA, November 1997 and *Verification and Validation of HPAC 3.0*, Logicon R and D Associates for DSWA, June 1998.

19 *Initial Validation of VLSTRACK Version 1.5 and Version 2.0*, Jaycor for Naval Surface Warfare (NSWC) Division Dahlgren, December 1993, *Verification of VLSTRACK Version 1.5 and Version 2.0*, Jaycor for NSWC Dahlgren, October 1994, and *Final Validation of VLSTRACK Version 1.6.1*, Jaycor for Chemical Biological Defense Division, Wright-Patterson AFB, April 1998.

Field Trial Data Should Be Able To Distinguish Between Models: Part I

- **Substantial differences were observed even after accounting for initial conditions and effects assumptions**
  - Surface deposition, concentration, and biological warfare agent dosages
- **For comparisons to field trial data (validation), methodologies should be consistent**
- **Desired field trial conditions and methodologies**
  - Longer-range, lower-level measurements: crosswind, downwind, and upwind
  - Instantaneous releases
  - Analysis of uncertainty must be included
  - Arc-wise maxima, crosswind integrated, time-averaged measures
    - » Measures of uncertainty where feasible
  - Sensitivity analyses

FIELD TRIAL DATA SHOULD BE ABLE TO DISTINGUISH BETWEEN MODELS: PART II

One method that should be incorporated into future model evaluation efforts is to plot the model residuals (differences between model predictions and field trial observations) as a function of several key variables. Key variables might include, for instance, sampling or averaging time, atmospheric stability, wind speed, mixing height, and ground surface characteristics. A properly functioning model should not show any trends in these plots. The occurrence of a trend across a specific key variable would indicate the need for modification to the model. Several examples of the reasonable incorporation of uncertainty into the evaluation of air quality models exist.[20]

The incorporation of an independent expert (with the aid of the model experts) to conduct the comparative analyses using relatively new data (i.e., not previously analyzed in detail by either model proponent) would offer the most credible result.

Previously analyzed data sets[21] could satisfy some of the requirements for very long-range measurements. Several shorter-range (<10 Km) data sets exist and have, in many cases, been previously examined.[22] For shorter-range comparisons (≈ 1 Km), it is expected that any model or model upgrade should be consistent with the generally accepted Pasquill-Gifford-Turner stability curves for plume dispersion at least for the simpler releases. Therefore, validation efforts should probably show comparisons between model predictions and the associated PGT dispersion curves, where appropriate.

Our casual (non-exhaustive) search for data that satisfy some or most of the requirements discussed here, in particular, ranges of between 10 and 100 Km, has yielded the data sets that are briefly described on the accompanying slide.[23]

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20 *Air Quality Model Evaluation and Uncertainty*, S. R. Hanna, JAPCA, Volume 38, No. 4, April 1988, pages 406-412; *Confidence Limits for Air Quality Model Evaluations, as Estimated by Bootstrap and Jackknife Resampling Methods*, S. R. Hanna, Atmospheric Environment, Volume 23, No. 6, 1989, pages 1385 – 1398; *Hazardous Gas Model Evaluation with Field Trial Observations*, S.R. Hanna, J.C. Chang, and D.G. Strimaitis, Atmospheric Environment, Volume 27A, No. 15, 1993, pages 2265 – 2285; and *Evaluation of VLSTRACK with the Prairie Grass Field Data*, J.C. Chang (unpublished CSI 709 Term Project for Professor S. R. Hanna), George Mason University, 30 November 1998.

21 For example, ANATEX = Across North America Tracer Experiment (1987) and ETEX = European Tracer Experiment (1994).

22 These data sets include Phase I Dugway data, the Prairie Grass data set, and several buoyant plume data sets. Recently a comparison of HPAC and VLSTRACK to the Phase I Dugway data set has been completed. See *HPAC Versus VLSTRACK Operational Comparison,* E.L. Hines, SAIC, January 1999.

23 The ASCOT data set involves complex terrain and it may be the case that neither model, by itself, is appropriate for such a situation. The LROD data set has already been compared, at least in part, to VLSTRACK.

Field Trial Data Should Be Able To Distinguish Between Models: Part II

- **Desired field trial conditions and methodologies (continued)**
  - Plots of residuals as a function of key variables can be valuable
  - Comparisons should be conducted by an independent expert

- **Potential data sets (10 - 100 Km)**
  - Phase II Dipole Pride 26 (Nevada test site, SF_6)
  - Cape Canaveral NOAA MVP (Model Validation Program) 1995 - 1996
    - » SF_6, ground and upper air
  - OLAD (Over-Land Atmospheric Diffusion) Dugway, September 1997
    - » SF_6 surface and airborne line releases
  - LROD (Long-Range Over-water Diffusion) July 1993
    - » Northwest of Kauai, HI; SF_6, ground and upper air
  - ASCOT (Atmospheric Studies in Complex Terrain) Rocky Flats

RECOMMENDATIONS

In order to improve the contribution of NBC hazard model predictions to chemical/biological (CB) defense, several initial steps seem appropriate.

First, where feasible, source term assumptions should be standardized. For example, there does not appear to be a good reason for the two models to assume, at least as defaults, different values for agent purity, dissemination efficiency, biological agent decay rate, or mass median droplet diameter for the same scenario. Likewise, standardization of effects definitions and assumptions between models would appear to be a reasonable first step.[24] Standardization, as described above, will also lead to reduced differences between model results.

Ultimately, confidence in any model's accuracy will be based on the credibility and success of its validation effort. The best chance for a credible comparison of predictions to field trial data – validation – will require the use of similar and appropriate scientific methodologies for both hazard prediction models. Any validation methodology must include an uncertainty analysis and should probably be conducted by an independent expert – possibly with the aid of the model proponents where required.

Improving the contribution of these models to CB defense will require continued emphasis on matching the model features (e.g., required inputs, outputs, connectivity) to the capabilities and limitations of the prospective operational users. This "matching of operational needs" is likely to be most important for users at the tactical level.

Finally, the use of hazard prediction models *and* their outputs should be institutionalized throughout the CB defense community. This "institutionalization" should necessarily include the standardization of doctrine, the teaching of hazard model usage at the military schools, improvements in local training, and the enhancement of the representation of CB play in major training exercises.

[24] We recognize that the development and approval of standardized lethality/effects assumptions for military personnel, perhaps especially for lower-level effects, is not trivial. Nonetheless, this appears to represent an area that could greatly improve the consistency and usefulness of these models.

Recommendations

In order to improve the contribution of hazard model predictions to CB defense

- **Standardize source terms and effects models, where feasible**
- **Continue to validate models against field trial data**
  - Use similar and appropriate methodologies
  - Include uncertainty analyses
  - Conducted by a relatively independent expert
- **Improve the models to better match the capabilities and limitations of the prospective operational users**
- **Institutionalize the use of hazard models and their results throughout the community**
  - Standardize doctrine for use of models and results
  - Teach at appropriate military schools
  - Improve local training programs
  - Enhance representation of CB play in major training exercises

APPENDIX A
USER SURVEY RESULTS

APPENDIX A
USER SURVEY RESULTS

The next 10 slides and 10 text pages provide some additional details associated with our survey of actual and potential users. In addition to a few additional methodological details, this appendix provides our detailed observations at the tactical level.

Given the operational focus of the study established by the sponsor, there was a need to understand better the operating environment of the users. In developing the scenarios to be used in comparing the models, we needed to understand the types of decisions the model outputs would be used to support, the inputs that would typically be available for use by the operators, as well as other constraints, such as typical response times that have to be met, the backgrounds and qualifications of available operators, and available computing capability.

The technique we elected to use to develop this information, given the time constraints imposed by the task, was an informal survey of model users. To facilitate the selection of a reasonable sample of model users we queried each of the model developers for a suggested list of their users. We then selected a sample from the lists provided by the model developers. Where necessary, we supplemented the original list based on information developed during the survey process.

Initially we identified three categories of users of hazard prediction models. "Researchers" are those users who are primarily responsible for developing the technology upon which the models are based, as well as the models themselves. The "Studies" community includes those users who employ the models in support of NBC-related studies, e.g., weapons systems analyses, and force structure studies. "Operational" users are those who use the models in support of operational planning and real-time decision making.

Since the study was focused on "operational" users, and to facilitate discussions concerning that category, we decided to classify these users as either "strategic," "operational," or "tactical."

"The "Strategic" level contains users that normally support national decision making, and includes organizations such as the DIA, CIA, and Joint Staff.

The "Operational" level contains those users that are primarily involved in planning and supervising the execution of military campaigns, and includes the combatant commands, such as EUCOM, PACOM, SOCOM, STRATCOM.

The "Tactical" level contains those users that are typically involved in planning for and conducting combat operations. In the Army this includes forces at Corps and below. In the Air Force, it includes numbered air forces, wings and squadrons, and airbases. In the Navy, it would include task forces, ships, and shore installations.

Appendix A
User Survey Results

- **Focus of study on operational users**
- **Informal survey with users identified by model developers**
- **Segmented users into several categories**
  - Research
  - Studies
  - Operational
- **Assigned operational users to one of several levels of command to facilitate discussions of operating environments and needs**
  - Strategic (national, Joint Staff, DIA, CIA)
  - Operational (major combatant command, CINC, JTF)
  - Tactical (Corps and below, ships, airbases)

SURVEY OF OPERATIONAL USERS

From among the lists of potential users provided by the model developers, and information developed by the study team as the survey progressed, the following organizations were selected for the survey: the Joint Staff, EUCOM, CENTCOM, PACOM, SOCOM, USASOC, ACOM, LANTFLT, USFK/EUSA, I Corps, III Corps, the 4th Infantry Division, V Corps, XVIII Airborne Corps, and the 82nd Airborne Division. Some of these organizations were visited by team members, while in other cases, telephone interviews were conducted.

From discussions with representatives of these organizations we were able to obtain (1) a better understanding of the extent to which the models were being used by these various organizations, (2) in those instances when the models were being used, an understanding of which models were being used, and what kinds of activities were being supported, (3) a description of the operating environments in which the models were being used, and (4) a better appreciation for the needs of the users, and the constraints they faced.

We made no attempt to conduct a rigorous statistical sampling of all operational users. Rather, the objectives of our informal survey were to determine if, and how, the models were being used, and to learn about the operating environments and factors that might influence model use and utility.

Survey of Operational Users

- **Conducted an informal survey (either by personal visit or by phone) of primary NBC officers at major commands**
  - Joint Staff *
  - EUCOM
  - CENTCOM
  - PACOM
  - STRATCOM
  - SOCOM/USASOC *
  - ACOM
  - LANTFLT
  - USFK/EUSA *
  - I Corps
  - III Corps *
  - 4th Inf Division *
  - V Corps
  - XVIII Airborne Corps*
  - 82nd Airborne Division *

- **Objectives**
  - Determined whether models were being used and, if so, how
  - Discussed operating environments
  - Identified user priorities and needs for CB hazard prediction
  - Not a rigorous headcount of users

* Personal visits

USER OBSERVATIONS: DISTRIBUTION OF OPERATIONAL USERS

Prior to the start of our survey, we were given the impression that the two models, HPAC and VLSTRACK, were in common use among operational users, and that impression was certainly reinforced by the lists of users initially provided by the two model groups. But our survey actually identified relatively few operational users of the two models. And most of the users identified were at the strategic and operational levels, e.g., DIA, STRATCOM, CENTCOM, USFK, and SOCOM.

While we generally did not find operational users at the tactical level, we did find a strong interest in the use of models at that level. One apparent reason that the models are not generally used at the tactical level is concern about their legitimacy. That is, several senior NBC officers indicated to us that they could not in good conscience employ such a model in developing advice for their commanders since the models did not have official DoD approval – this in spite of the existence of the 1996 Hollis-Prociv memo. Other users, however, did not seem to be concerned about this issue.

User Observations: Distribution of Operational Users

- **We did not identify many <u>operational</u> users of either HPAC or VLSTRACK**
- **Most of the operational users identified were at the strategic and operational levels**
  - DIA
  - Some CINCs (STRATCOM, CENTCOM, USFK, SOCOM)
- **Strong interest in models encountered at tactical levels, but very limited use to date**

USER OBSERVATIONS: MODEL USAGE

Among those users identified, all indicated that their model of choice was HPAC. VLSTRACK, when employed, was usually used as a backup, particularly in situations when there was some question raised about the validity of the HPAC prediction. We did not encounter any user who employed VLSTRACK as the preferred model.

The basis for preference stated was usually the availability of specific capabilities provided by HPAC that were not available through VLSTRACK, e.g., direct portrayal of terrain and infrastructure, the modeling of chemical/biological weapons facilities, the modeling of nuclear or radiological weapons, relatively easy access to weather data (near real-time and historical).

One phenomenon that we encountered during our search for operational users was that the use of models was often dependent on the personalities involved. For example, we might be told that a particular officer at a headquarters was a frequent user of a given model. But when we tried to contact the individual, we might find that he had recently transferred and that the models were no longer being used at that location. Likewise, we found locations where the models had not traditionally been in use until a particular individual had been assigned to the organization.

User Observations: Model Usage

- **Among the users at the strategic and operational levels that employed the models**
  - HPAC was the clear model of choice
  - VLSTRACK was usually used in backup mode

- **Basis for preference appeared to be the availability of specific capabilities, such as the ability to portray terrain and infrastructure, modeling of chemical/biological weapon facilities, nuclear and radiological weapons, relative ease of access to weather data (near real-time and historical)**

- **Use of models at operational levels frequently dependent on personalities (EUCOM, PACOM, USFK, 82nd ABD)**

USER OBSERVATIONS: OPERATING ENVIRONMENTS

Early in our survey process we detected that there were significant differences among the operating environments of operational users at the three levels being investigated. These differences have to do with the focus of effort of the NBC staffs at the three levels, the opportunities that each level has to engage in activities that require CB hazard predictions, the skills and backgrounds of the people generally available to operate the models and explain the resulting predictions, the ability of the organization concerned to maintain adequate skills among its assigned personnel, and an organization's access to contractor support.

- At the strategic and operational levels, the models are used primarily to support *operational planning*, whereas at the tactical level we envision (based on visits with potential users) that the primary focus will be on *real-time predictions* of hazards due to CB attacks launched by enemy forces. This difference in focus has a significant impact on the response times required, as well as the nature and source of inputs that are usually available and used to produce the predictions.
- The opportunities to employ the models, and hence maintain adequate familiarity, also are likely to vary significantly between the strategic/operational and the tactical levels. In the case of the former, it was not unusual to find that the models were used almost daily. Whereas at the tactical level, we envision (again, based on visits with potential users) that opportunities, governed primarily by the frequency of major training exercises, would be few and far between.
- The skills and backgrounds of available personnel assigned to the various levels also varied considerably. At the strategic/operational levels, it is more likely to find readily available personnel who have the specific skills that are needed to employ these models effectively, e.g., specialists in MET, are more likely to be found. At the tactical level, however, there was considerable concern about the ability to acquire and retain personnel with sufficient backgrounds to operate the models and properly interpret their results.
- The ability of the strategic/operational user to maintain adequate skills is significantly better than that of users at the tactical level. This is a direct result of several factors: differences in opportunities to employ the models, turnover of personnel, and availability of adequate training programs.
- Several of the users at the strategic/operational levels have access to contractor personnel to operate the models. This seemed to alleviate many of the personnel problems previously mentioned. It is not envisioned that such a capability would exist at the tactical level.

User Observations: Operating Environments

- **There are significant differences in the operating environments of potential users at the various levels involving**
  - Focus of effort
  - Opportunities to use models
  - Skills and backgrounds of available personnel
  - Ability to maintain adequate skills
  - Access to contractor support

USER OBSERVATIONS: PROCESSES AND PROCEDURES

In general, we found little evidence, at any of the levels surveyed, of standardization, or institutionalization, of the CB hazard prediction process, or the use of models such as HPAC or VLSTRACK, in particular. Clearly the use of models, such as HPAC or VLSTRACK, at the strategic and operational levels, provides some degree of standardization. But our discussions with users at these levels did not indicate that there was any unifying doctrine, or procedures, concerning the development or use of hazard predictions. For example, we were frequently told that the military school system does not teach hazard prediction with models, or the use of either of the two models in question. It is anticipated that a common doctrine could contribute to reducing the variance in outcomes when different headquarters assess the same hazard prediction situation.

There was an almost universal call for better model training programs that would address not only the needs of model operators, but also those of the ultimate customer. Current training programs were criticized for not providing sufficient depth of understanding for model operators. It was emphasized that future programs should be capable of being conducted frequently and locally.

The operational users we interviewed all indicated a need to be able to address in their analyses toxicity levels well below those normally considered "militarily significant." Their concerns had legal and moral foundations and they considered the need to address peacetime incidents or accidents.

Also in the area of training, concern was expressed about the adequacy of the NBC activities portrayed in most training exercises.

User Observations: Processes and Procedures

- **Little evidence of standardization, or institutionalization, of**
  - Use of models
  - Use of model outputs
- **Need for better training programs**
  - For model operators
  - For end-users of model outputs
  - That can be conducted frequently and locally
- **Operational users interested in assessing toxicity levels well below what is considered "militarily significant"**
  - Legal
  - Moral
  - Peacetime incidents
- **Need to improve portrayal of CB activities during major training events**

OBSERVATIONS AT THE TACTICAL LEVEL

There were some observations that appeared to be unique to the tactical level, or at least predominantly an issue at that level. They will be addressed in the following charts.

As indicated previously, HPAC and VLSTRACK are not generally in use at the tactical level. Instead, units surveyed use some form of NATO ATP-45, or an equivalent technique, to develop predictions to support initial warnings of potential hazards. None of the units visited were completely satisfied with this approach, however. For while such a technique is timely, these units said it is too conservative to support subsequent decision making. As a result they are frequently unable to respond adequately to the needs of the commanders and staffs that they support. In the process, they become irrelevant to the tactical situation, and this is the source of much frustration at this level. Users at this level felt that a model that would allow them to reduce the uncertainty associated with the ATP-45 process could potentially contribute significantly to CB defense.

Observations at the Tactical Level

- Currently rely on NATO ATP-45, or its equivalent
- ATP-45 and similar techniques provide timely initial warnings, but are too conservative for subsequent decision making
- Failure to be responsive to commanders' needs undermines credibility and minimizes role in decision process
- Community frustrated by inability to be relevant

OBSERVATIONS AT THE TACTICAL LEVEL (cont'd)

At the present time no real operational concept for the employment of models such as HPAC or VLSTRACK exists at the tactical level. However, we did discuss how such models might be used. The main theme that evolved from these discussions was the use of the models to reduce the uncertainty associated with initial predictions based on techniques such as the ATP-45, or its local equivalent, so that the time to conduct an effective NBC reconnaissance and survey could be minimized.

Users at the tactical level repeatedly stated the need for any useful hazard prediction model to be fully compatible with current command and control systems. In the case of the heavy ground forces visited, this is the Maneuver Control System (MCS). The lack of compatibility between the present command and control systems and the existing prediction means, such as ATP-45 and ANBACIS, contribute to their lack of utility.[1] It is important to these users that they be able to develop hazard predictions quickly, and overlay the prediction on other existing displays, e.g., friendly order of battle, infrastructure, without disturbing the other displays. They also need to be able to transmit these displays to other organizations along the tactical Internet.

For tactical ground forces in particular, it is very important that the results of the hazard prediction be portrayed in the context of terrain and the friendly order of battle.

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1 The Automated Nuclear, Biological, and Chemical Information System (ANBACIS) is an automated implementation of ATP-45 and was inserted into MCS in the 1980s.Users reported that the system has not been fully developed or supported.

Observations at the Tactical Level (cont'd)

- A principal objective in use of models would be to reduce reconnaissance and survey time
- Hazard prediction capability needs to be compatible with existing C2 system, e.g., maneuver control system
- Prediction needs to be seen in context of terrain and friendly order of battle

OBSERVATIONS AT THE TACTICAL LEVEL (cont'd)

In light of the typically short response times associated with the situations encountered at the tactical levels, there was considerable interest in the ability to automate the inputs needed to develop hazard predictions. Of particular concern to us was the availability of MET data. All of the tactical users indicated a strong desire to use the USAF MET support that is available to them both in peacetime and during combat operations. None of the tactical users were willing to rely on MET servers located at places such as Monterey, Offutt, or DTRA. The USAF MET squadrons supporting Army combat forces (corps, divisions) provide periodic MET to the supported unit via the local tactical Internet. We discussed the possibility that complex, timely data could be provided in the format needed by models such as HPAC or VLSTRACK. This is an option that needs more attention if these models are to be of much value at the tactical level.

At the tactical level, considerable time is spent planning smoke operations. In fact, considerably more time is devoted to smoke operations than CB operations. Therefore there was a great deal of interest expressed by users at this level in the ability of hazard prediction models to contribute to this activity.

While our primary focus was on the use of hazard prediction models in support of combat operations, all of the users at the tactical level expressed interest in using the models to support contingency planning for potential "peacetime" incidents, such as highway or train accidents. All of the sites visited described potential situations in and around their installations that could create very serious conditions.

Observations at the Tactical Level (cont'd)

- Need to be able to automate key inputs, e.g., MET, to meet short response times
- Interest in use of models for planning smoke operations
- Interest also expressed in using models to plan for and respond to "peacetime" incidents

OBSERVATIONS AT THE TACTICAL LEVEL (cont'd)

A topic that came up repeatedly during discussions with potential users at the tactical level involved the difficulty they envisioned in acquiring and maintaining the skills required to operate the models and use their outputs intelligently. We were informed that neither the models nor their employment was taught in the military school system. Furthermore, significant turnover of key personnel, and the lack of adequate training programs, at these levels made it difficult to maintain skills once they were acquired.

And finally, there was concern about the ability to use the models effectively in a force that consisted of elements equipped with digital and non-digital equipment.

Observations at the Tactical Level (cont'd)

- **Considerable difficulty acquiring and maintaining skills required to operate models and use outputs intelligently**
  - Models (HPAC, VLSTRACK) not taught at schools
  - Use of models for hazard prediction not taught at schools
  - Significant personnel turnover
  - Lack of adequate training programs
- **Need to operate with digital and non-digital units**

APPENDIX B
DETAILED ANALYSES: MODEL COMPARISONS

APPENDIX B
DETAILED ANALYSES: MODEL COMPARISONS

The next 87 text pages and 87 slides provide the detailed comparisons of HPAC 3.1 and VLSTRACK 1.63 predictions. For each set of scenarios, model results using default settings are presented, followed by a second set of results in which "similar" settings were used. The first 64 pages and slides present the results of our comparisons of three chemical weapon scenarios. First, we examine the dispersal of 1,000 Kg of GD (Soman) from a sprayer at 100 m (31 pages and 31 slides). Three fixed wind speeds were examined – 4, 15, and 30 Kph – all blowing from the north-northeast. This chemical weapon release is postulated to take place in southern Iraq at 1500 local time on 29 September under a clear sky and with barren, dry, desert conditions.

The second chemical case (10 pages and 10 slides) that we investigated involves a 152mm artillery barrage of GB (Sarin). This scenario is postulated to take place in South Korea, near Seoul at 0700 local time on 23 October. The environment is considered forested and overcast with a fixed wind of 8 Kph out of the west-northwest.

A medium range ballistic missile carrying 500 Kg of the nerve agent VX or thickened VX (TVX) is examined next (23 pages and 23 slides). Four burst altitudes were considered – VX at 300 and 1,000 m and TVX at 1,000 and 10,000 m. These bursts are assumed to occur in western Virginia (latitude 39 north and longitude 78 west) under partly cloudy skies over grasslands with a 13 Kph wind blowing from the south-south west at 1200 local on 30 October.

The next 23 text pages and 23 slides examine biological agent dispersal comparisons. First, an aerial sprayer, similar to the one studied for the GD case, that dispenses BWA, BWB, or BWC is investigated (15 pages and 15 slides). This event is postulated to occur at 0200 local on 6 November at the same southern Iraq location described for the GD sprayer trial. A 15 Kph wind out of the north-northeast and dry, clear sky, barren, desert conditions were assumed.

Next, a ballistic missile with 50 submunitions that contains BWA, BWB, or BWC is studied (8 pages and 8 slides). This release occurs at 1300 local on 16 November at the same Korean location studied earlier, although this time the environment is considered grassland and overcast with a 6 Kph wind out of the west-northwest or a time-variable wind.[25]

Next, 64 pages of tables (Appendix C) that describe the initial conditions (input parameter values) for each of the comparative trials are provided.

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25 Reasonable temperatures, and in some cases wind speeds and directions, were extracted from average values provided in *The Weather Handbook*, Conway Publications, Atlanta, GA, 1963.

Appendix B
Detailed Analyses: Model Comparisons

- **Chemical weapon trials**
  - GD from sprayer
  - GB from 152mm artillery
  - VX and thickened VX from a ballistic missile
- **Biological agent weapon trials**
  - Biological warfare agent A (BWA), B (BWB), and C (BWC)
  - Aerial sprayer
  - Ballistic missile with submunitions

COMPARATIVE OBSERVATIONS FROM SPRAYER WITH GD TRIALS

With respect to surface deposition, higher level (greater than LD20 from skin contact) area size predictions of both HPAC and VLSTRACK were, in general, less than 1 Km^2. **For many applications, these predictions might be considered quite similar. However, the lower level predictions of surface deposition that were presented by the two models differed significantly.** The HPAC-presented LD2 (7 mg/m^2) area sizes grew to between 2 and 9 times the size of the reported VLSTRACK 7 mg/m^2 area sizes. HPAC predicted that significant deposition continues to occur after the initial ("splat") event. In addition, HPAC predicted some upwind deposition for the slowest wind speed that was examined; VLSTRACK did not. The cause of these low-level differences appears to be related to fundamental differences in the way in which each model attempts to communicate the fate of the predicted cloud, and hence deposited chemical. By "turning off" the HPAC feature that includes the meandering component of the modeled turbulence, we were able to generate somewhat smaller HPAC-predicted areas. (See the predictions based on the HPAC T_{avg} = 0 trials.) Similarly, by ignoring the VLSTRACK Pasquill stability category default value and choosing the "Very Unstable" category, we could generate larger predicted VLSTRACK predicted deposition areas.

In general, the area sizes corresponding to low level concentrations (0.01 $\mu g/m^3$) **that were presented to the user** by HPAC were much larger than the corresponding reported VLSTRACK values.[26]

The center of the HPAC-predicted cloud traveled further, for the same initial fixed wind, than did the VLSTRACK cloud center. Our analysis suggests that, when a single wind speed observation is used, differing wind speed-height profiles or differing vertical distributions of cloud material, or, as a minimum, differing assumed average cloud center advection speeds are assumed by the two models. The VLSTRACK concentration predictions showed evidence of a secondary evaporation trail at the 0.01 $\mu g/m^3$ level, especially for the slower wind speed case. For this case, the HPAC predictions showed evidence of a secondary evaporation concentration trail only at lower concentration levels.

For predicting dosages, HPAC and VLSTRACK employ different effects assumptions and present different measures of "lethality" and "effectiveness." Our analyses has shown that by using the same effects assumptions, the apparent variability in the predicted dosages can be somewhat reduced.

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26 The HPAC reported mean area – a different metric from the area presented to the user when the mean value toggle is engaged – is, in general, significantly smaller than the reported VLSTRACK concentration area for this sprayer trial comparison.

Comparative Observations From Sprayer With GD Trials

- **Deposition**
  - Similar higher concentration (mg/m^2) level footprint
  - HPAC leads to bigger LD2 areas
  - Lower concentration level (LD2) HPAC deposition areas continue to grow with time
  - Significant upwind deposition at low wind speed for HPAC prediction only
- **Concentration**
  - Comparable HPAC areas are much larger
  - HPAC distance traveled is somewhat longer
  - VLSTRACK shows evidence of secondary evaporation trail
- **Dosage**
  - Predicted area sizes varied somewhat when default inputs were used, **however all areas were less than 1 Km^2**
  - Standardizing the source and effects assumptions (as best as we could) led to similar dosage area sizes

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 15 Kph) DEFAULT SETTINGS: SURFACE DEPOSITION

The chart opposite shows a comparison of the surface deposition predicted by VLSTRACK 1.6.3 and HPAC 3.1. This comparative scenario considered a sprayer at an altitude (above ground level – AGL) of 100 m that dispensed 1,000 Kg of GD evenly across an 800 m line. In this case, a fixed wind of 15 Kph from 15 degrees was assumed. Whenever reasonable, the individual model's default input values were used.

On the left of the chart, the HPAC predictions are shown at 2 minutes and at 4 hours. The HPAC contours shown correspond to the assumed lethal dosage (LD) based on skin contact chemical agent toxicity (percutaneous). For this representation, it is assumed that the exposed human skin area is 1 m^2. On the right of the chart, the VLSTRACK surface deposition prediction at 2 minutes is shown. For this comparison, the VLSTRACK contours (in mg/m^2) – 7, 22, 50, and 170 – were set equal to the HPAC default contours – LD2, LD20, LD50, and LD90.[27]

The HPAC display was generated by invoking the "mean value" toggle on the HPAC output screen. The length (L) and width (W) of the HPAC area, approximately an ellipse, were measured and the area was estimated.[28] The predicted VLSTRACK area is estimated in two ways. First, the reported area, for example, 0.436 Km^2 for the 22 mg/m^2 contour, was used. Next, we measured the length and width of the VLSTRACK output and computed the "observed" area (based on approximating the deposition shape as a rectangle). We refer to this area as the "measured" value and it is reported in red on the chart.

The 2-minute HPAC prediction of area size at LD2 (7 mg/m^2) is about 77 percent larger than the VLSTRACK prediction. The relative contour area sizes, that is, the relationship between the individual HPAC contour level areas and the relationship between the individual VLSTRACK contour level areas appear similar. In both cases, the LD2 areas are less than 1 Km^2 at 2 minutes. At 4 hours, the HPAC LD2 area grows to 1.79 Km^2. There is no such observation for the VLSTRACK prediction. In other words, the VLSTRACK predicted area does not get any larger than the size shown at 2 minutes.

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27 "LD2" corresponds to the dosage that would be assumed lethal for 2 percent of the exposed population. See *Initial Verification and Validation of HPAC 1.3*, DSWA-TR-96-88, November 1997, page 58. VLSTRACK does not directly compute skin contact hazard because of the wide range in type of clothing and amount of exposed skin to consider.

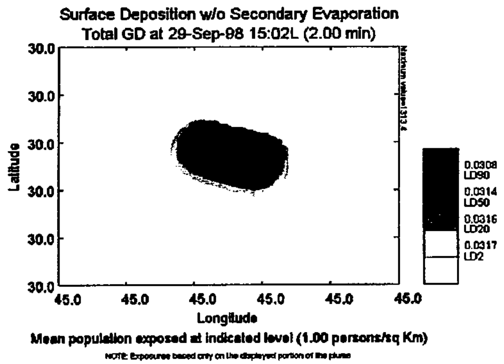
28 For this estimate (in Km^2), the area was modeled as an ellipse, and therefore, area = $LW\pi/4$.

1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 15 Kph) Default Settings: Surface Deposition

HPAC

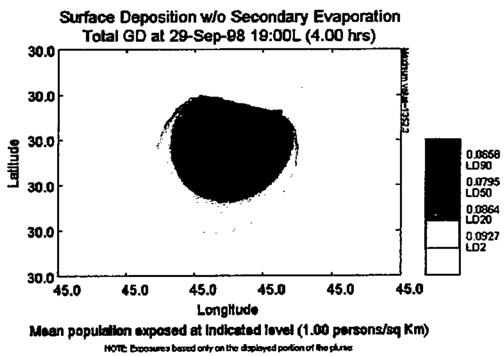
2 minutes

L*W =
0.79 *
1.34



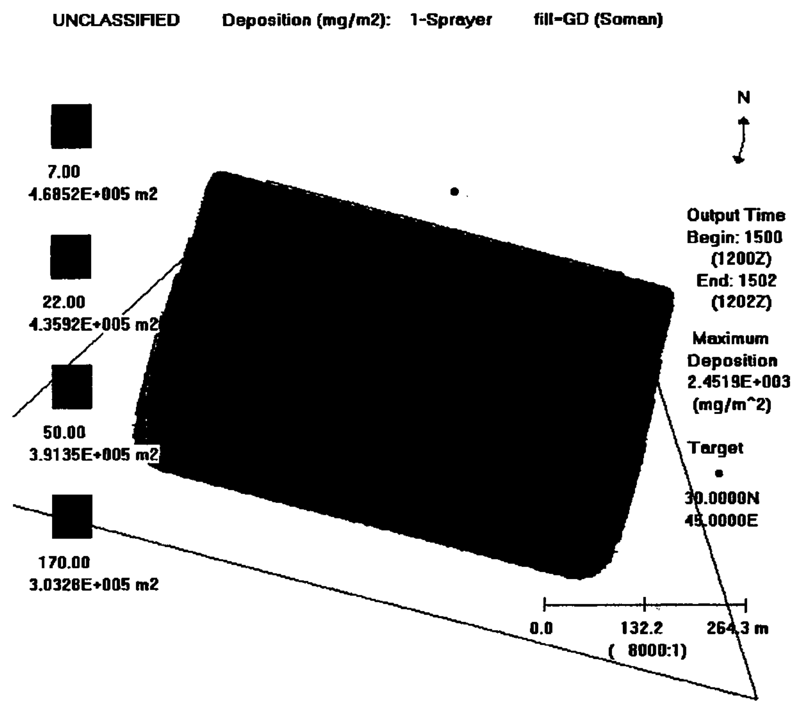
4 hours

L*W =
1.58 * 1.44



VLSTRACK

2 minutes



Different scales shown

At 7 mg/m^2 Estimated Area (Km^2)	HPAC (2 min/4 hr)	VLSTRACK {measured}
	0.83/1.79	0.47 {0.27}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 4 Kph) DEFAULT SETTINGS: SURFACE DEPOSITION

For surface deposition, HPAC offers three types of plots. First, the fate of the liquid component can be plotted. As a function of time, these plots will show the effects of evaporation – the liquid "pool" will gradually disappear. Both models showed this effect of evaporation on the liquid pool. Next, the fate of the vapor can be plotted in HPAC. Finally, the total plot, vapor and liquid, can be plotted. In this case the effects of secondary evaporation are not included in the plot. Our 2-minute "total" plots basically correspond to the area size of the initial liquid pool – probably most consistent with what VLSTRACK presents. The area sizes at LD2 shown for the plots at 4 hours basically correspond to the surface deposition due to vapor GD. VLSTRACK does not consider this type of deposition.

The chart shown on the opposite page uses the same format as the last chart. In this case, a fixed wind of 4 Kph was examined. The 2-minute HPAC prediction of area size at LD2 (7 mg/m^2) is about 4.4 times larger than the VLSTRACK prediction. However, in both cases, the LD2 areas are less than 1 Km^2 at 2 minutes. As was true in the 15 Kph case, the 4-hour HPAC LD2 area grows, in this case to 1.40 Km^2.

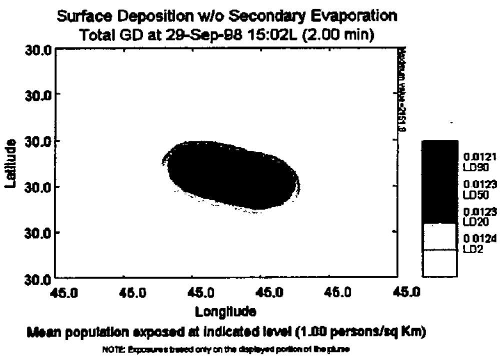
On the HPAC displays, a line that ends with a triangle corresponds to the initial source term – an 800 m line. It can be seen that for this 4 Kph case, a significant amount of deposition occurs upwind of the source ("behind" the line relative to the fixed wind out of 15 degrees).

1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 4 Kph) Default Settings: Surface Deposition

HPAC

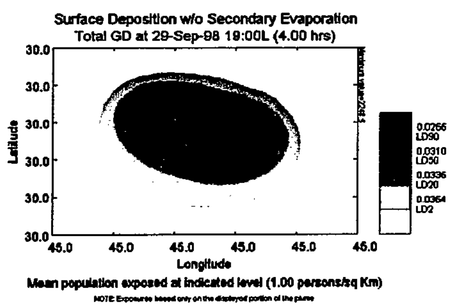
2 minutes

L*W =
0.69 * 1.32



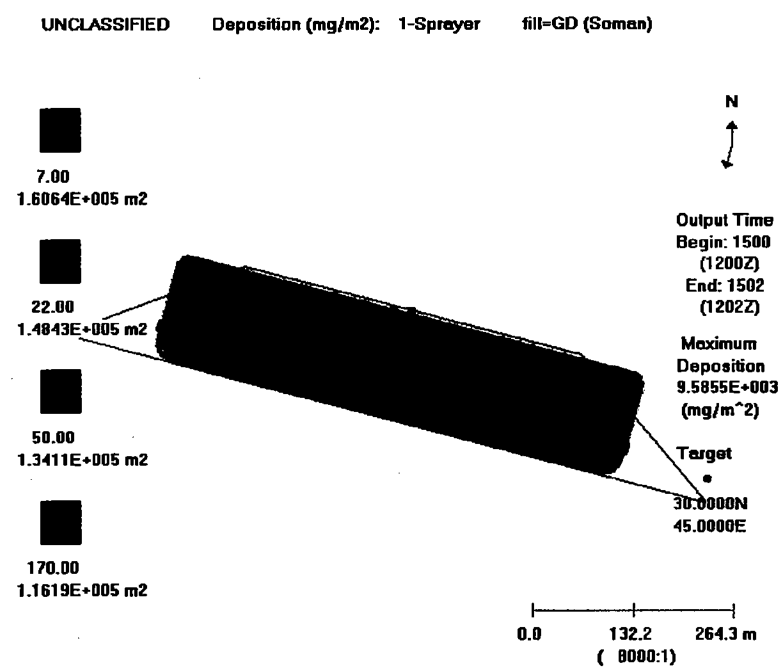
4 hours

L*W =
1.17 * 1.53



VLSTRACK

2 minutes



Different scales shown

At 7 mg/m^2 Estimated Area (Km^2)	HPAC (2 min/4hr)	VLSTRACK {measured}
	0.71/1.40	0.16 {0.10}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 30 Kph) DEFAULT SETTINGS: SURFACE DEPOSITION

The fixed wind GD sprayer scenario was also examined with a fixed wind of 30 Kph. The 2-minute HPAC prediction of area size at LD2 (7 mg/m^2) is about 65 percent larger than the VLSTRACK prediction.[29] The 4-hour HPAC LD2 area grows to 2.69 Km^2.

In all three sprayer cases that we examined, the measured VLSTRACK area (shown in braces and in red) was smaller than the reported VLSTRACK area. We contacted the developers of VLSTRACK and reported this observation. The developers responded via e-mail with the following.[30]

> We have recently been notified of errors in the screen display for Windows 95/NT operation of VLSTRACK. Our contractor is trying to fix the problem for VLSTRACK 3.0. We are not planning on modifying VLSTRACK 1.6.3.

For the rest of this analysis, we assume that the reported value is the correct, comparable value for VLSTRACK. However, at least for this sprayer scenario, we will continue to document the measured VLSTRACK values (in red braces). We note, importantly, that it is these measured values that best represent what the graphical display "shows" the user. At the conclusion of this section, a comparison of area sizes for VLSTRACK (reported and measured) is briefly discussed.

The solid lines shown on the VLSTRACK figure and drawn at ± 15 degrees from the plume center correspond to the assumed wind direction error. This assumed wind direction error is an operator input for VLSTRACK. For all VLSTRACK calculations in this study, we kept this value at ± 15 degrees. These same solid lines can be seen on the previous two VLSTRACK figures.

---

29 In this case, the 2-minute HPAC area was modeled as a rectangle. The black braces { } denote this assumption – as opposed to our typical elliptical assumption.

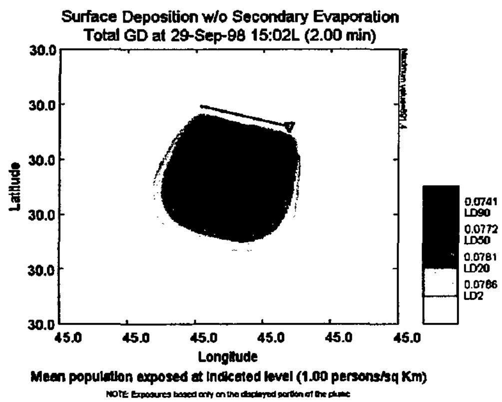
30 Electronic mail from Tim Bauer, Naval Surface Warfare Center, Dahlgren Division, Dahlgren, VA, 26 October 1998.

1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 30 Kph) Default Settings: Surface Deposition

HPAC

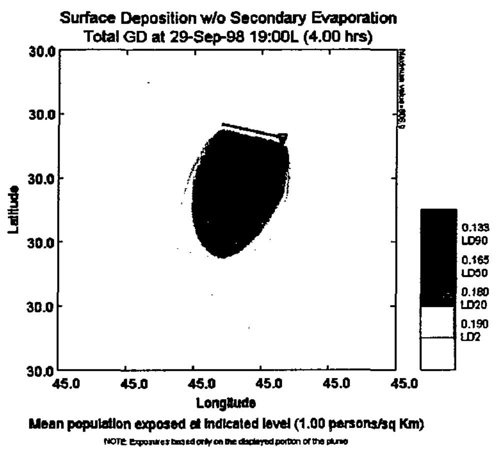
2 minutes

L*W =
1.28 * 1.28



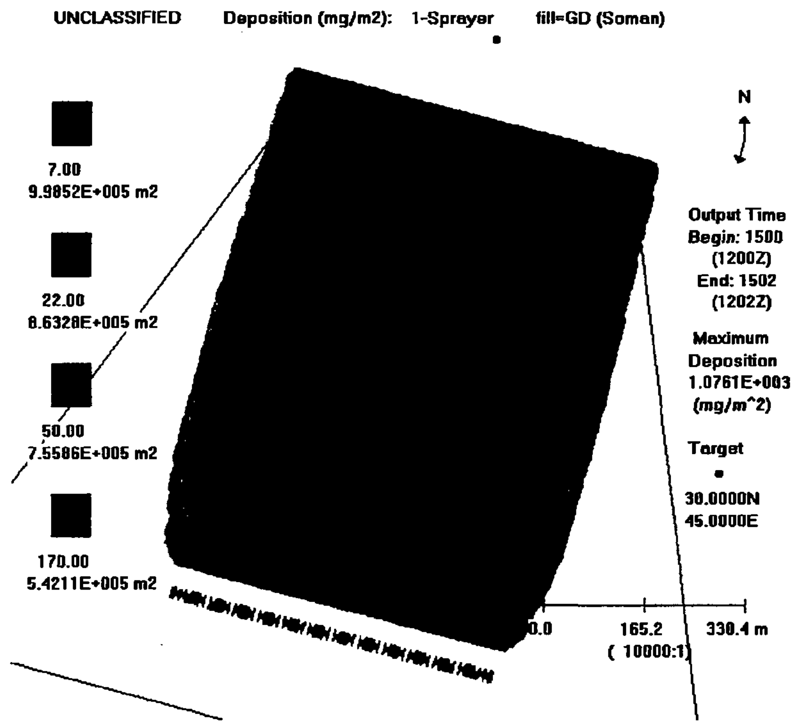
4 hours

L*W =
2.39 * 1.43



VLSTRACK

2 minutes



Different scales shown

At 7 mg/m² Estimated Area (Km²)	HPAC (2 min/4hr)	VLSTRACK {measured}
	{1.65}/2.69	1.00 {0.58}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 15 Kph) DEFAULT SETTINGS: CONCENTRATION (1.8 m)

The chart opposite provides a comparison of HPAC and VLSTRACK concentration predictions at 1 and 4 hours. The table at the bottom of the chart reports the *measured* distance traveled from the initial source location and the measured length and width of the concentration ellipses. In addition, this table provides the reported and measured VLSTRACK area sizes at the 0.01 μg/m^3 level (at an AGL of 1.8 m). For HPAC, the measured/estimated area is reported in black (based on using the "mean value" HPAC output toggle) and a "mean area" is provided in red brackets [ ]. The developers of HPAC have provided the following definitions of these two area size estimates.[31]

- Area of the Mean Dosage (AMD) – The area in which the mean dosage is greater than some critical value (e.g., LCt50). This value is calculated from the contour based on using the average dosage values at each grid point (dbar{x,y}). **This corresponds to the value of the area shown in the graphics display when the user employs the "Mean Value" toggle in HPAC.**
- Mean Area – For each realization of the turbulent wind field, a set of dosage values at each grid point (d{x,y}) can be computed. From this dosage field, a dosage area at a specified value can be estimated. The average of these dosage areas, computed in this way over all of the turbulent wind fields considered, is defined here as the mean area. **This estimate corresponds to the area reported by HPAC in red as the "Mean Population Exposed" (at a given level or higher) for an assumed density of 1 person per Km^2.**

The size of the predicted HPAC AMD areas at 0.01 μg/m^3 is approximately 2.8 and 3.6 times larger than the corresponding reported VLSTRACK areas, at 1 and 4 hours, respectively. The 4-hour VLSTRACK (elliptical) prediction is more eccentric than the 4-hour HPAC prediction. That is, the VLSTRACK 4-hour length (downwind) is significantly larger than its width (crosswind). This is not the case for the HPAC prediction.

The 1-hour VLSTRACK prediction shows evidence, a small tail at the 0.01 μg/m^3 level lagging the main ellipse, of what we believe is secondary evaporation. At the levels examined here, HPAC did not show this tail. For this case, this secondary evaporation tail was visible at lower levels in HPAC output (e.g., at 1 hour and 0.0001 μg/m^3).

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31 Electronic mail from R. Ian Sykes, ARAP Group, Titan Corp., Princeton, NJ, 29 October 1998.

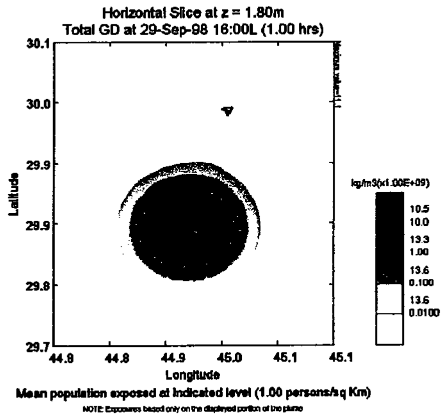
1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 15 Kph) Default Settings: Concentration (1.8 m)

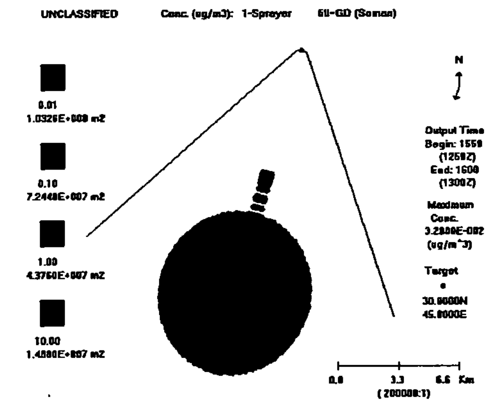
HPAC

VLSTRACK

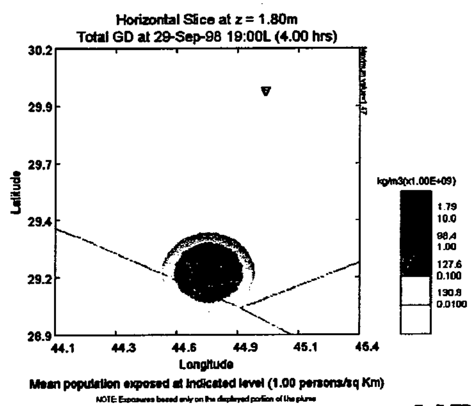
Different scales shown

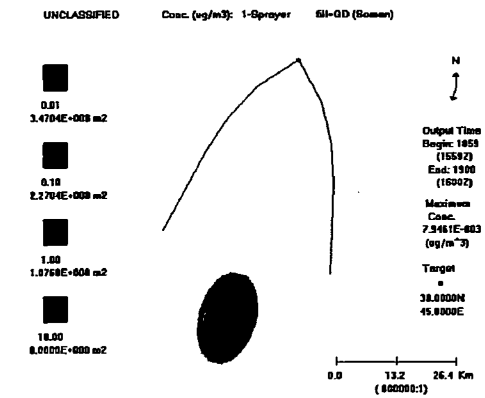
1 hour





4 hours





At 0.01mg/m^3 (1 hr/4 hr)	**HPAC** [Mean Area]	**VLSTRACK** {measured}
Distance from Start (Km)	18.1/92	13/60
Length (Km)	19.4/39.7	9.2/20.6
Width at Half Length (Km)	18.6/40.2	8.3/8.9
Estimated Area (Km^2)	284/1,254 [14/131]	103/347 {20/144}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 4 Kph) DEFAULT SETTINGS: CONCENTRATION (1.8 m)

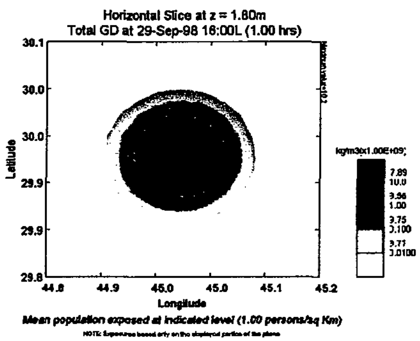
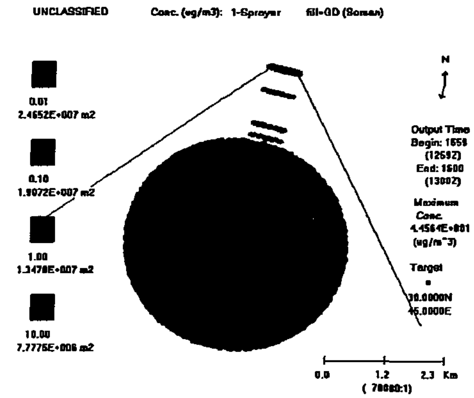
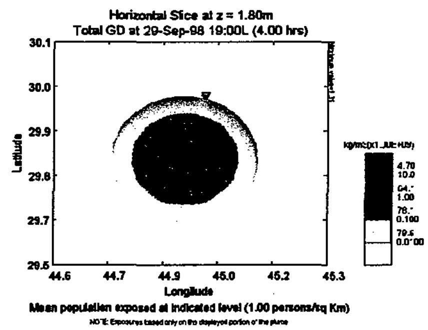
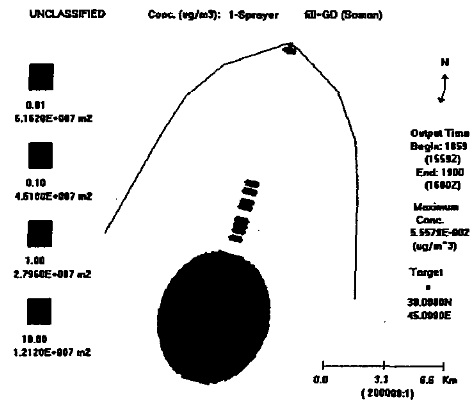
The chart opposite provides a comparison of HPAC and VLSTRACK concentration predictions at 1 and 4 hours for a fixed wind of 4 Kph. As was the case for the 15 Kph winds, the HPAC AMD areas are much larger than the reported VLSTRACK areas. Again, the VLSTRACK-predicted ellipses are more eccentric than the corresponding HPAC ellipses. The HPAC area sizes estimated by the "mean area" technique are similar to those reported by VLSTRACK. A review of the 15 Kph case shows that the HPAC mean area values were much smaller than the corresponding VLSTRACK area.

The VLSTRACK prediction shows evidence of a secondary evaporation trail. We re-examined this VLSTRACK trial using the "rigorous calculation" toggle as opposed to the "rapid approximation" toggle. The rapid approximation technique represented our default value. The results were quite similar. The main difference was that a detailed contour structure within the secondary evaporation trail was predicted.

The HPAC prediction did not show evidence of a secondary evaporation trail at the 0.01 $\mu g/m^3$ level. However, at lower contour levels (a few orders of magnitude), the HPAC predictions did show evidence of what appeared to be secondary evaporation concentration trail.

1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 4 Kph) Default Settings: Concentration (1.8 m)

Different scales shown

	HPAC	VLSTRACK
1 hour		
4 hours		

At 0.01mg/m^3 (1 hr/4 hr)	**HPAC** [Mean Area]	**VLSTRACK** {measured}
Distance from Start (Km)	5/20	5/16
Length (Km)	18.4/39.1	5.7/7.4
Width at Half Length (Km)	17.9/38.2	5.9/6.0
Estimated Area (Km^2)	258/1,175 [10/86]	25/62 {27/35}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 30 Kph) DEFAULT SETTINGS: CONCENTRATION (1.8 m)

The predicted concentration values for the case with a 30 Kph fixed wind is shown on the accompanying chart. The comparative results are similar to those discussed for the 4 and 15 Kph cases. In this case, the HPAC AMD area sizes at 0.01 $\mu g/m^3$ are 1.8 and 1.6 times larger than the reported VLSTRACK values for the 1 and 4 hour cases, respectively. The corresponding HPAC mean area values are much smaller. **Perhaps the most appropriate comparison of area sizes for these two models is represented by the HPAC AMD value, the estimated value displayed to the user when the mean value toggle is employed, and the VLSTRACK reported value.**[32]

All three cases indicate that the center of the predicted HPAC concentration cloud has moved further from the source than the VLSTRACK predicted cloud at the same times. For example, for the 4, 15, and 30 Kph cases at 4 hours, HPAC predicts a distance of 20, 92, and 192 Km and VLSTRACK predicts (via our measurement) distances of 16, 60, and 129 Km, respectively. These differences may be explained in two ways. First, the measured VLSTRACK distances are in error as confirmed to us by the developer. Our "back-of-the-envelope" estimate of this error, described later in this paper, suggests that the VLSTRACK distances at 4 hours for the 4, 15, and 30 Kph cases may be a factor of 1.307 larger, or 21, 78, and 169 Km, respectively.

A second cause of this "distance traveled" discrepancy may be due to differences in the assumed wind measurement heights – 2 m for VLSTRACK and 10 m for HPAC – and concomitant differences in the assumed wind speed-height profile. This is examined in the next set of scenarios in which the wind measurement heights are set equal to 10 m for both models.

---

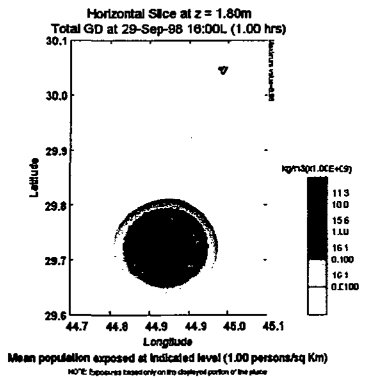
32 We would have used the VLSTRACK measured value, that is, the value that is consistent with the area size displayed graphically to the user, except that the VLSTRACK developers have confirmed to us that these values are in error. See the reference of footnote 21.

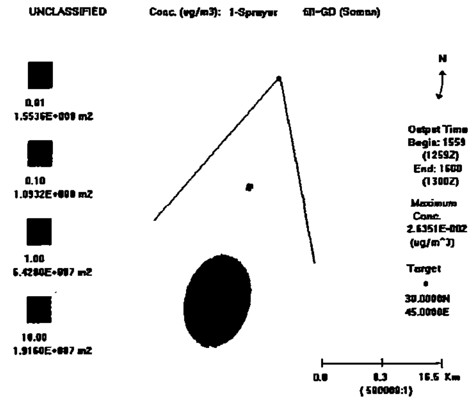
1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 30 Kph) Default Settings: Concentration (1.8 m)

HPAC | VLSTRACK

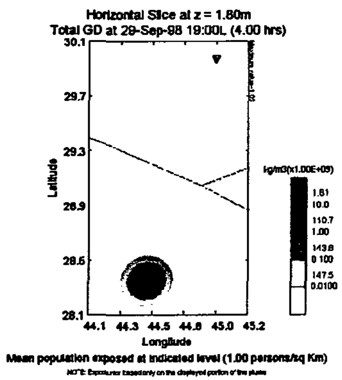
Different scales shown

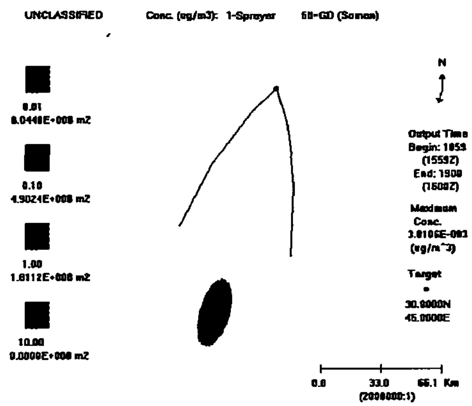
1 hour





4 hours





At 0.01mg/m³ (1 hr/4 hr)	HPAC [Mean Area]	VLSTRACK {measured}
Distance from Start (Km)	38/192	32/129
Length (Km)	19.8/43.3	12.9/37.0
Width at Half Length (Km)	18.5/38.3	6.4/16.6
Estimated Area (Km²)	288/1,303 [16/148]	156/804 {65/482}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 15 Kph) DEFAULT SETTINGS: DOSAGE (1.8 m / 8 hr)

The accompanying figures compare the HPAC and VLSTRACK integrated dosages that are predicted 8 hours after the sprayer incident. The assumptions associated with the lethality of GD, referred to here as the "effects" assumptions, are different for the two models. For example, the default HPAC output presents lethal concentrations at the 90 and 50 percent population level, LCt90 and LCt50.[33] The LCt50 contour corresponds to a chemical agent toxicity value of 70 mg-min/m^3. HPAC also presents incapacitation concentrations, ICt50 and ICt5, and a "threshold" contour assumed for miosis based on toxicity values of 0.16, 16, and 35 mg-min/m^3, respectively. The small figure to the left of the chart illustrates how long the HPAC-predicted miosis trail is for this case.

The default VLSTRACK contours are LCt2, LCt20, LCt50, and LCt90. The effects assumptions for LCt20, LCt50, and LCt90 contours in VLSTRACK are 29.781, 35.000, and 44.757 mg-min/m^3, respectively.

Since, for the default output settings, the HPAC ICt50 and VLSTRACK LCt50 contours are both based on 35 mg-min/m^3, the chart compares these area sizes. The HPAC AMD estimated area (0.43 Km^2) is 19 percent larger than the reported VLSTRACK area (0.36 Km^2). The reported VLSTRACK area is 38 percent larger than the HPAC mean area (0.26 Km^2). Both models predict areas that are less than 1 Km^2.

33 See *Initial Verification and Validation of HPAC 1.3*, DSWA-TR-96-88, November 1997, page 56.

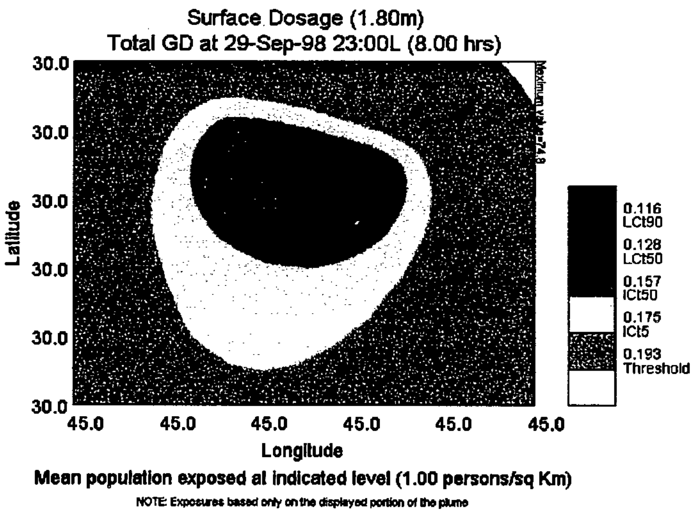
1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 15 Kph) Default Settings: Dosage (1.8 m / 8 hr)

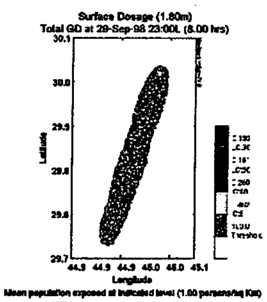
HPAC

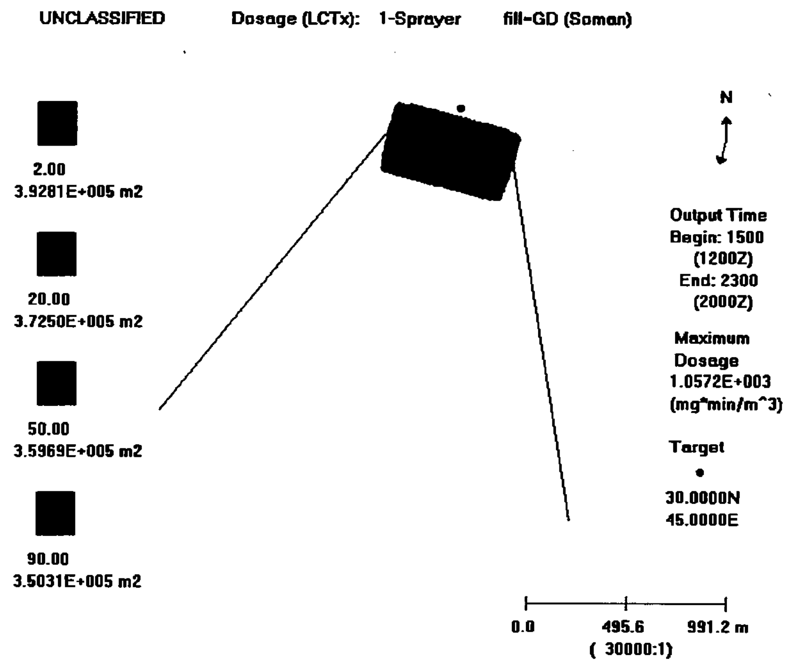
VLSTRACK

Different scales shown

ICt50 L*W =
0.64 * 0.86







At I/LCt50 (35 mg-min/m³) Estimated Area (Km²)	**HPAC** [Mean Area]	**VLSTRACK** {measured}
	0.43 [0.26]	0.36 {0.22}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 4 Kph) DEFAULT SETTINGS: DOSAGE (1.8 m / 8 hr)

For the 4 Kph dosage case, the predicted HPAC AMD area is about 3.2 times larger than the reported VLSTRACK area. This same trend, a much larger difference between the models at the lower wind speed, was also observed in our comparisons of surface deposition.

The reported VLSTRACK area is again about 38 percent larger [100% × (0.18-0.13)/0.13] than the HPAC mean area value.

A potentially important feature that distinguishes the two models, when operated in the "default" mode, at the slower wind speed, is the upwind dosage shown by HPAC but not by VLSTRACK.

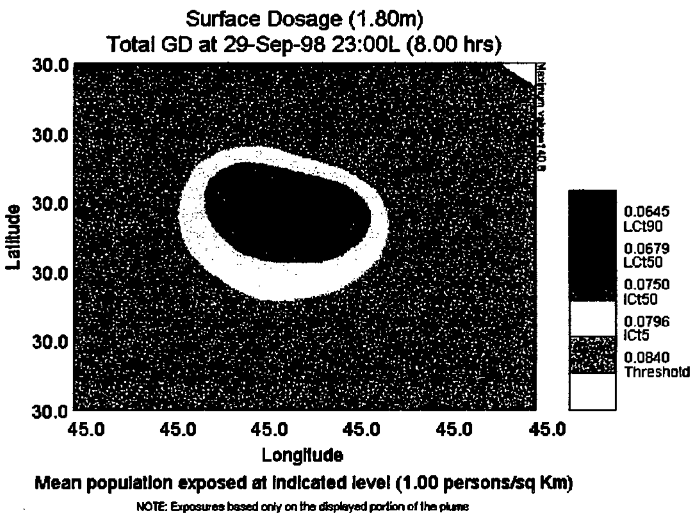
1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 4 Kph) Default Settings: Dosage (1.8 m / 8 hr)

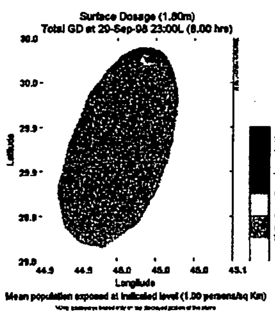
HPAC

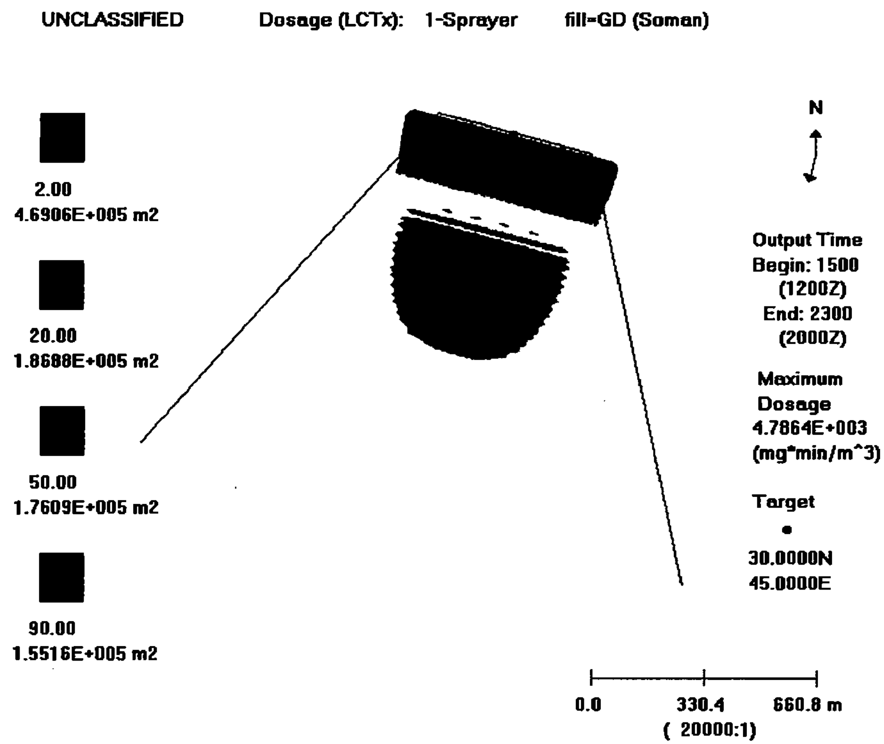
VLSTRACK

Different scales shown

ICt50 L*W = 0.71 * 1.02







At I/LCt50 (35 mg-min/m³) Estimated Area (Km²)	**HPAC** [Mean Area]	**VLSTRACK** {measured}
	0.57 [0.13]	0.18 {0.12}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 30 Kph) DEFAULT SETTINGS: DOSAGE (1.8 m / 8 hr)

At 30 Kph, the HPAC display shows no hazard of ICt50 or above. That is, the HPAC AMD area for ICt50 is 0.0. VLSTRACK reports an area size of 0.57 Km^2. HPAC does report a mean area value of 0.33 Km^2. In this case, the VLSTRACK reported area is 73 percent larger than the HPAC mean area.

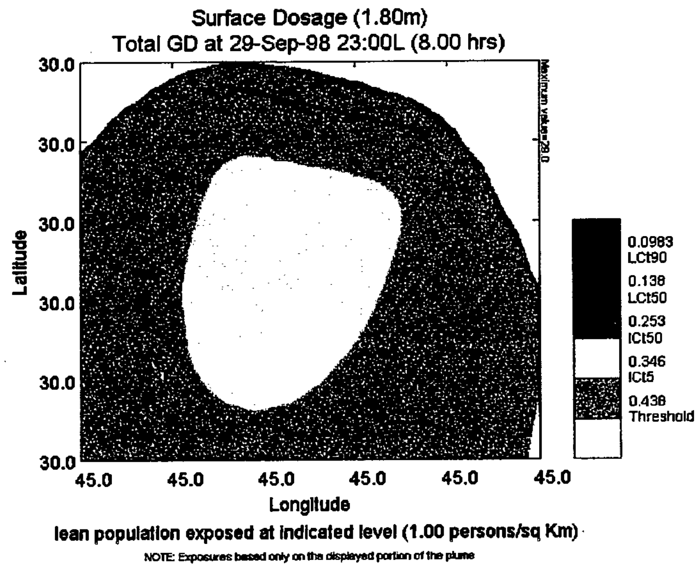
For our default sprayer case, it is important to note that at all three wind speeds, all area size estimates (HPAC AMD and mean area; VLSTRACK reported and measured) were less than or equal to 0.58 Km^2 – perhaps a small area for some tactical decisions. More to the point, the differences between the two models, with respect to dosage and perhaps deposition, might be considered quite small for many operational applications that one might imagine.

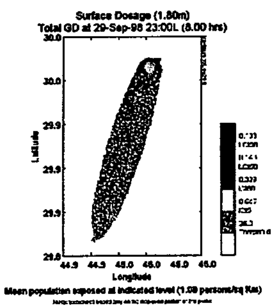
1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 30 Kph) Default Settings: Dosage (1.8 m / 8 hr)

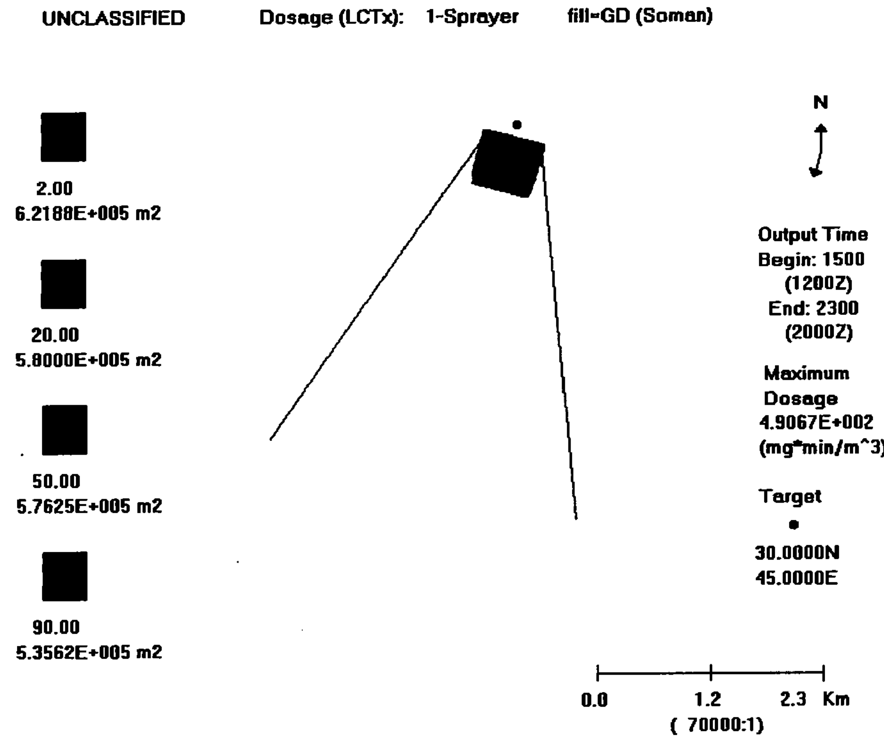
HPAC

VLSTRACK

Different scales shown







At I/LCt50 (35 mg-min/m³) Estimated Area (Km²)	HPAC [Mean Area]	VLSTRACK {measured}
	0 [0.33]	0.58 {0.34}

DEFAULT VS. "SIMILAR" SETTINGS FOR GD FROM SPRAYER TRIALS

To this point, the results of our default setting sprayer trials have been described. The table on the accompanying chart lists the changes that were made to these runs in order to create as similar a set of initial conditions as possible (at least as similar as we were able to create). In addition, for these "similar settings" comparisons, the HPAC output dosage contours were set at the VLSTRACK default effects assumptions levels – not at the HPAC default levels.

Default vs. "Similar" Settings for GD from Sprayer Trials

Model Parameter	*Default*		*"Similar"*	
	VLSTRACK	HPAC	VLSTRACK	HPAC
Lateral Sigma (m)	6	na	15	na
Initial Size (m)	na	15	na	15
Mass Median Drop Diameter (µm)	500	200	200	200
Distribution Sigma (µm)	1.7	2	2	2
Wind Measurement Height (m)	2	10	10	10

Effects assumptions were set equal to the reported VLSTRACK values (mg-min/m^3):

LCt5 = 25.527
LCt20 = 29.781
LCt50 = 35.000
LCt90 = 44.757

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 15 Kph) SIMILAR SETTINGS: SURFACE DEPOSITION

The comparative results shown on the chart opposite for the similar settings case are quite similar to the results shown for the default settings case. The 2-minute HPAC AMD LD2 value of 0.83 Km^2 is about twice the reported VLSTRACK value. For the corresponding default setting case, the HPAC AMD LD2 predicted value was 77 percent larger than the corresponding VLSTRACK reported value. As was true for the default settings case at 15 Kph, the 4-hour HPAC LD2 value grows beyond 1 Km^2.

1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 15 Kph) Similar Settings: Surface Deposition

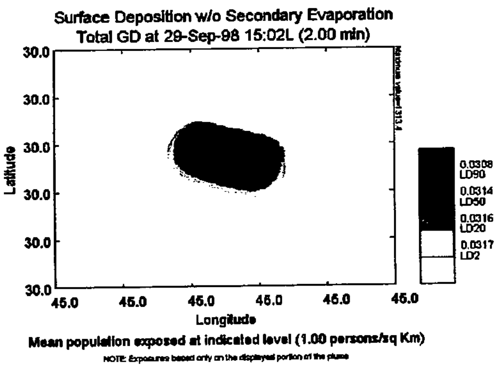
HPAC

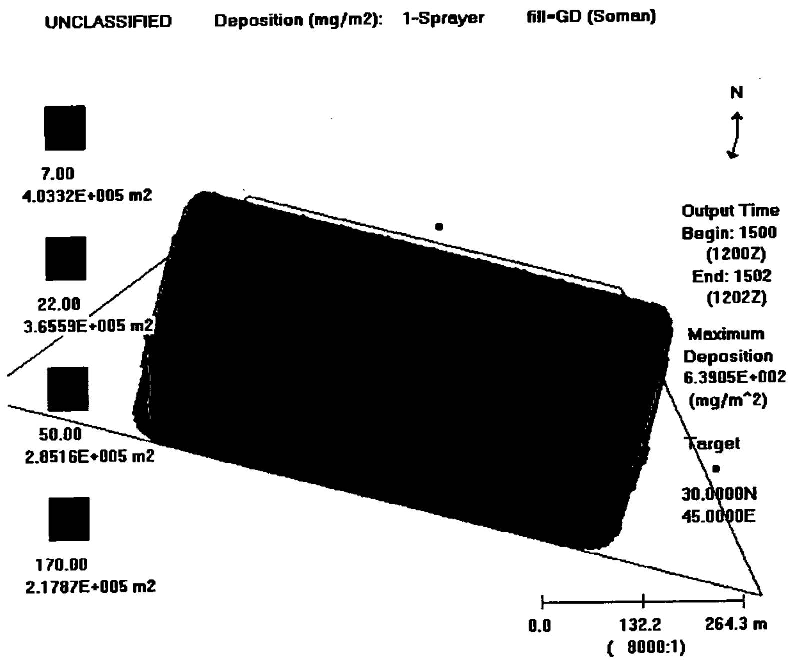
VLSTRACK

2 minutes

2 minutes

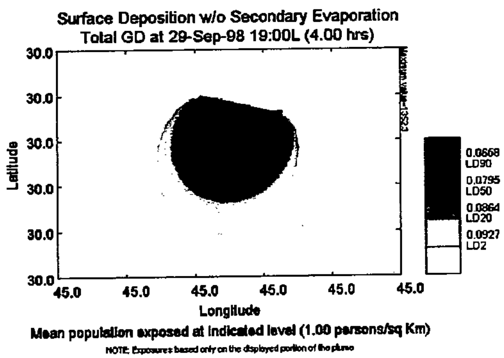
L*W =
0.79 * 1.34





4 hour s

L*W =
1.58 * 1.44



Different scales shown

At 7 mg/m² Estimated Area (Km²)	**HPAC (2 min/4 hr)**	**VLSTRACK** {measured}
	0.83/1.79	0.40 {0.23}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 4 Kph) SIMILAR SETTINGS: SURFACE DEPOSITION

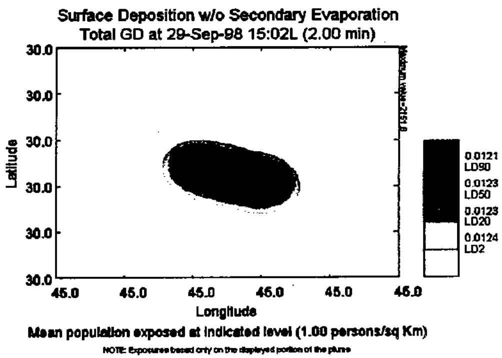
The comparative results shown on the chart opposite for the similar settings case are virtually identical to the results shown for the default settings case.

1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 4 Kph) Similar Settings: Surface Deposition

HPAC

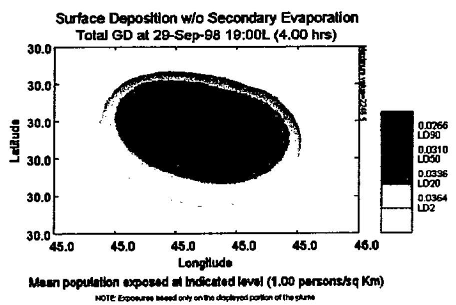
2 minutes

L*W =
0.69 * 1.32



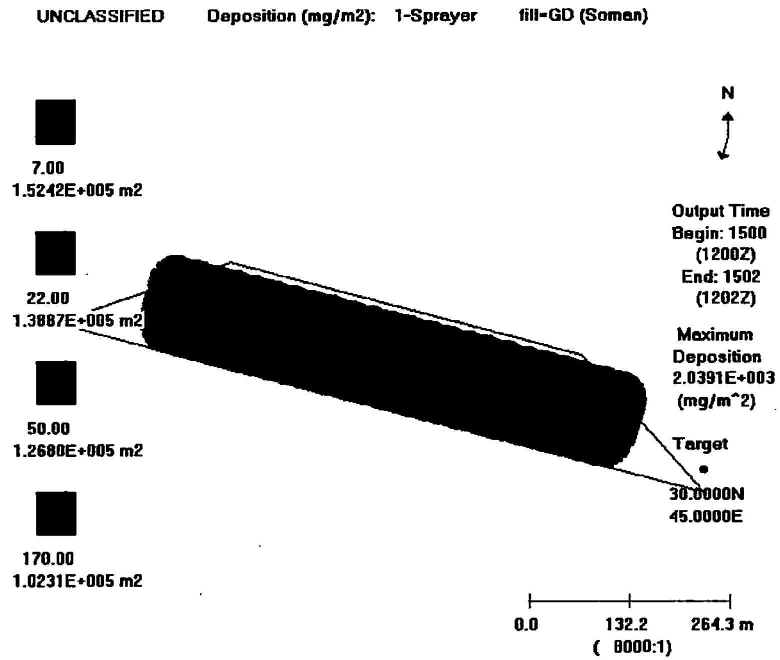
4 hour s

L*W =
1.17 * 1.53



VLSTRACK

2 minutes



Different scales shown

At 7 mg/m^2 Estimated Area (Km^2)	HPAC (2 min/4hr)	VLSTRACK {measured}
	0.71/1.40	0.15 {0.08}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 30 Kph) SIMILAR SETTINGS: SURFACE DEPOSITION

The comparative results shown on the chart opposite for the similar settings case are quite similar to the results shown for the default settings case. In this case, the HPAC AMD value at LD2 is 2.1 times larger than the reported VLSTRACK area.

1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 30 Kph) Similar Settings: Surface Deposition

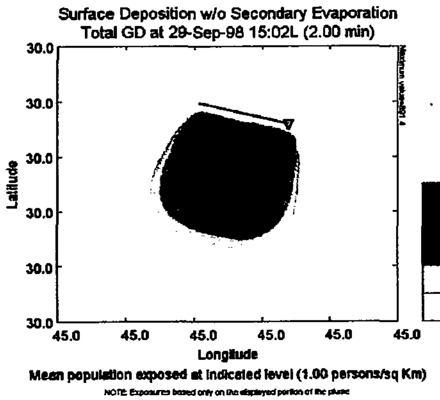
HPAC

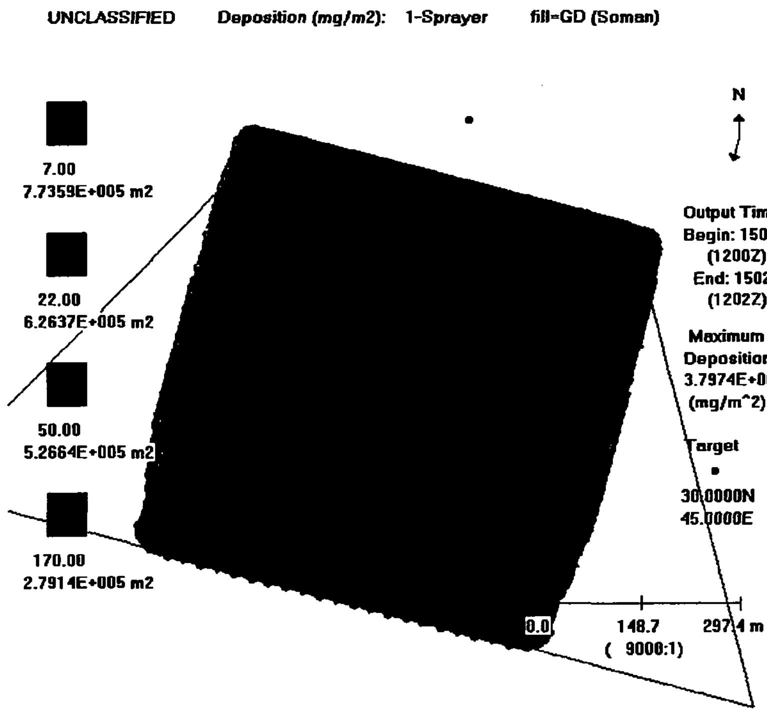
VLSTRACK

2 minutes

2 minutes

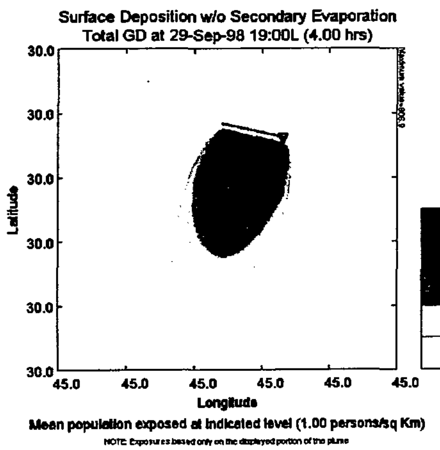
L*W =
1.28 * 1.28





4 hour s

L*W =
2.39 * 1.43



Different scales shown

At 7 mg/m² Estimated Area (Km²)	**HPAC (2 min/4hr)**	**VLSTRACK** {measured}
	{1.65}/2.69	0.77 {0.45}

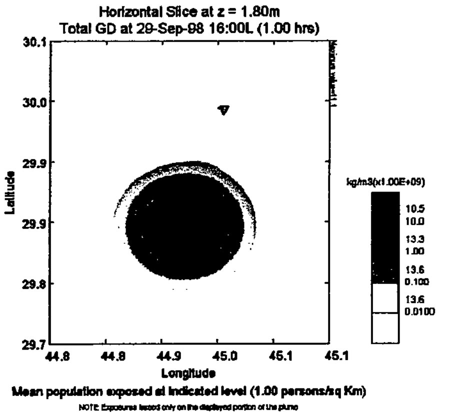
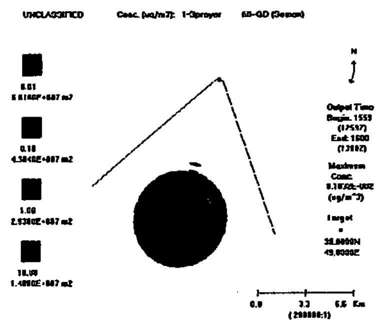
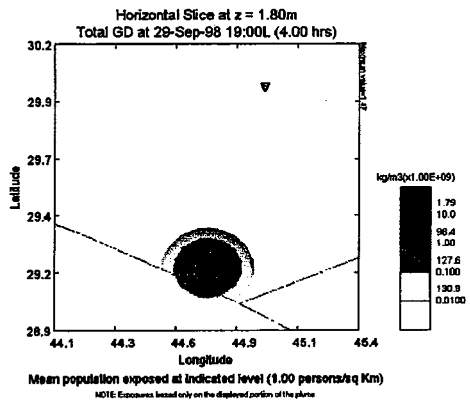
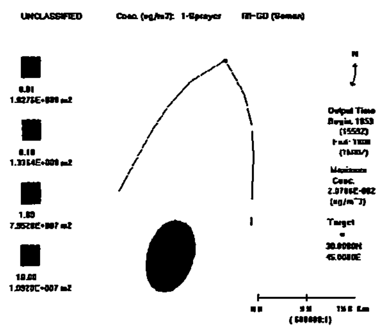
1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 15 Kph) SIMILAR SETTINGS: CONCENTRATION (1.8 m)

The comparative results shown on the chart opposite for the similar settings case are quite similar to the results shown for the corresponding default settings case. In fact, the HPAC results are identical, since no input parameters have been changed. However, the VLSTRACK results have changed.

First, relative to the default settings case, the VLSTRACK 0.01 $\mu g/m^3$ areas are smaller, by almost half, and hence, there are even larger differences between VLSTRACK and HPAC. Next, the distances traveled by the VLSTRACK cloud are much shorter than those traveled by the HPAC cloud. After our rough correction for the plotting errors inherent in VLSTRACK 1.6.3, we compute a distance traveled by the center of the VLSTRACK cloud at 4 hours of about 51 Km. For this similar settings case, the wind measurement height was set at 10 m for both HPAC and VLSTRACK. As expected, moving the assumed VLSTRACK wind measuring height from 2 to 10 m, "slows" down the cloud. This is because both models assume that, given no additional information, wind speeds will increase with altitude. That is, the wind speed at a given height will decrease in the case where the wind measurement is assumed to be at 10 m relative to 2 m (for the same wind speed observation).

The suggestion of the observed differences in cloud transport downwind for this rather simple case is that HPAC and VLSTRACK model the wind speed-height profile, for the same single wind observation, differently. Alternatively, differing models of the vertical distribution of cloud material between simulations, even for the same assumed wind speed-height profile, could lead to the observed differences in cloud center transport. A final, and perhaps simplest explanation (related to our first speculation), is that VLSTRACK and HPAC, for the same initial fixed wind input, assume different average advection speeds for the center of mass of the cloud.

1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 15 Kph) Similar Settings: Concentration (1.8 m)

	HPAC	VLSTRACK
Different scales shown		
1 hour		
4 hours		

At 0.01mg/m³ (1 hr/4 hr)	**HPAC** [Mean Area]	**VLSTRACK** {measured}
Distance from Start (Km)	18.1/92.4	10/39
Length (Km)	19.4/39.7	6.8/15.0
Width at Half Length (Km)	18.6/40.2	6.4/9.4
Estimated Area (Km²)	284/1,254 [14/131]	58/193 {34/111}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 4 Kph) SIMILAR SETTINGS: CONCENTRATION (1.8 m)

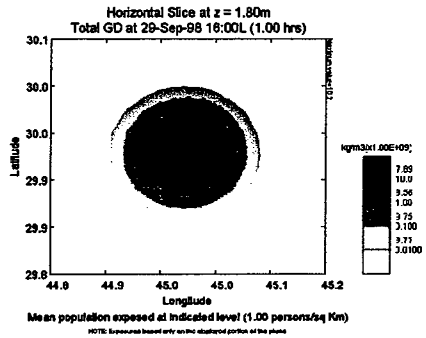
As was true at 15 Kph, the similar settings 4 Kph VLSTRACK area size prediction is somewhat smaller than the corresponding default setting case. Again, the HPAC areas at 0.01 $\mu g/m^3$ are significantly larger than the VLSTRACK predicted areas.

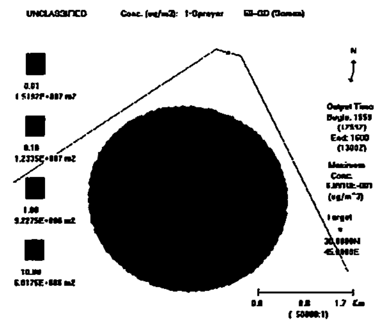
1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 4 Kph) Similar Settings: Concentration (1.8 m)

HPAC | VLSTRACK

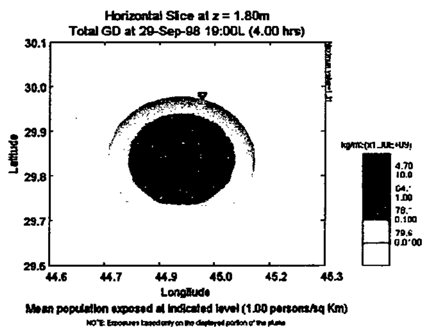
Different scales shown

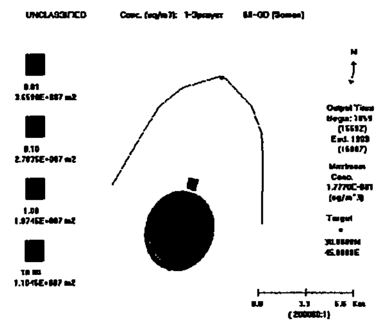
1 hour





4 hours





At 0.01mg/m³ (1 hr/4 hr)	HPAC [Mean Area]	VLSTRACK {measured}
Distance from Start (Km)	5/20	3 /11
Length (Km)	18.4/39.1	3.3/5.6
Width at Half Length (Km)	17.9/38.2	3.6/4.8
Estimated Area (Km²)	258/1,175 [10/86]	15/37 {9/21}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 30 Kph) SIMILAR SETTINGS: CONCENTRATION (1.8 m)

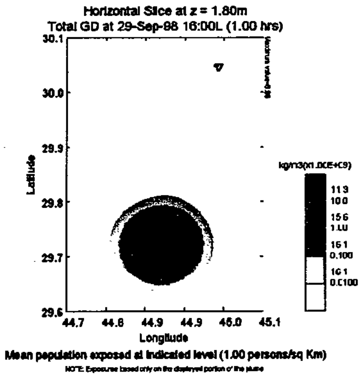
The results of the comparisons of concentration at 30 Kph appear to be consistent with the observations at 4 and 15 Kph. For example, the predicted VLSTRACK area sizes are smaller relative to the default settings case. The differences in VLSTRACK predicted area size, from the default to similar settings case, may, in part, be due to the change in the wind speed (resulting from a different measuring height) and the change in the mass median drop diameter from 500 to 200 μm.

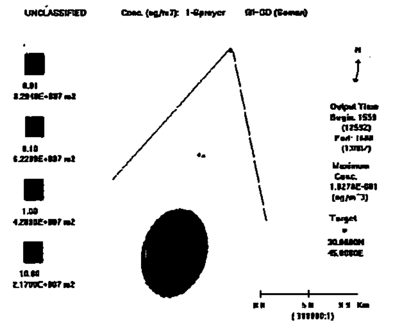
1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 30 Kph) Similar Settings: Concentration (1.8 m)

HPAC | VLSTRACK

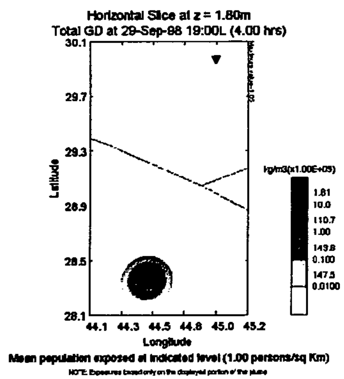
Different scales shown

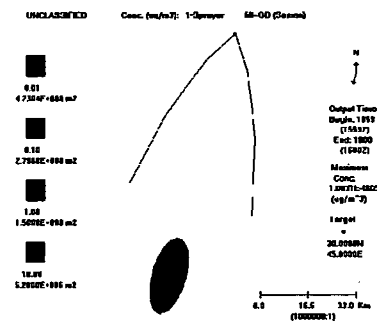
1 hour





4 hours





At 0.01mg/m³ (1 hr/4 hr)	**HPAC** [Mean Area]	**VLSTRACK** {measured}
Distance from Start (Km)	38/192	22/88
Length (Km)	19.8/43.3	9.4/27.0
Width at Half Length (Km)	18.5/38.3	6.4/11.9
Estimated Area (Km²)	288/1,303 [16/148]	83/423 {60/482}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 15 Kph) SIMILAR SETTINGS: DOSAGE (1.8 m / 8 hr)

The accompanying chart provides a comparison of the predicted 8-hour dosage for the two models. For this similar settings case, the same effects assumptions were used at each contour level. The HPAC AMD estimated area (0.57 Km^2) is 78 percent larger than the reported VLSTRACK area (0.32 Km^2). The HPAC mean area (0.30 Km^2) is 6 percent smaller than the reported VLSTRACK area. Both models predict areas that are less than 1 Km^2.

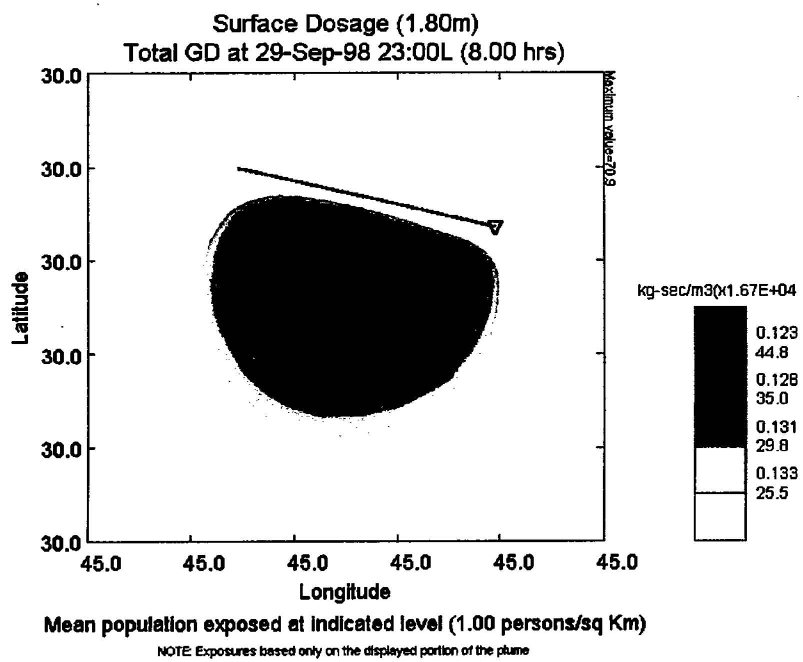
1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 15 Kph) Similar Settings: Dosage (1.8 m / 8 hr)

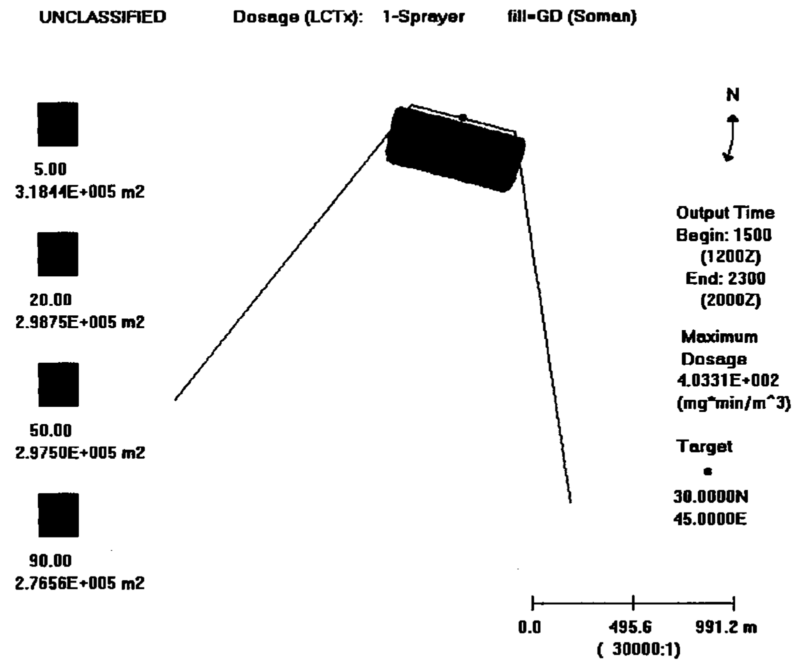
HPAC

VLSTRACK

Different scales shown

L*W =
0.81 * 0.90





At "LCt5" Estimated Area (Km^2)	**HPAC** [Mean Area]	**VLSTRACK** {measured}
	0.57 [0.30]	0.32 {0.18}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 4 Kph) SIMILAR SETTINGS: DOSAGE (1.8 m / 8 hr)

For the 4 Kph case, the HPAC AMD estimated area (0.68 Km^2) is 17 percent larger than the reported VLSTRACK area (0.58 Km^2). The reported VLSTRACK area is 3.6 times the size of the HPAC mean area (0.16 Km^2). Both models predict areas that are less than 1 Km^2.

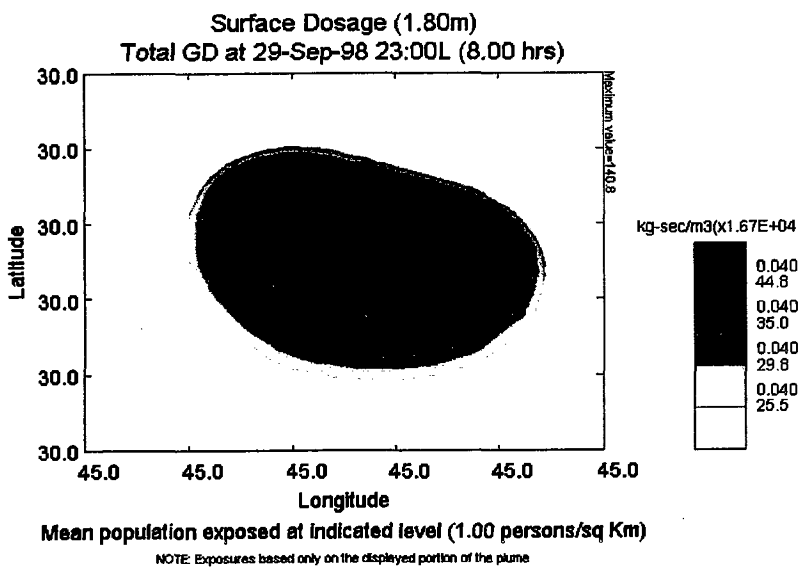
1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 4 Kph) Similar Settings: Dosage (1.8 m / 8 hr)

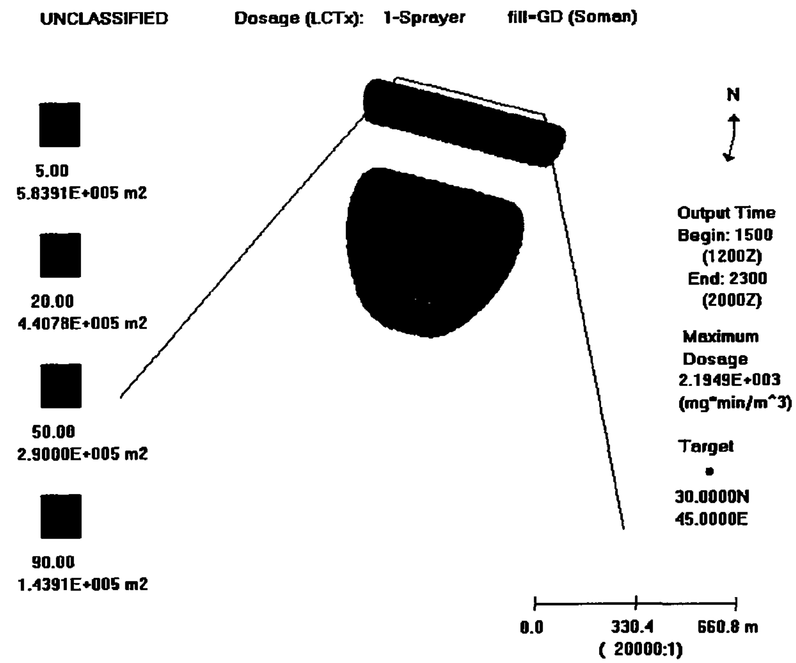
HPAC

VLSTRACK

Different scales shown

L*W =
0.79 * 1.10





At "LCt5" Estimated Area (Km^2)	**HPAC** [Mean Area]	**VLSTRACK** {measured}
	0.68 [0.16]	0.58 {0.32}

1,000 Kg GD (SOMAN) FROM SPRAYER AT 100 m AGL (800 m LINE) (FIXED WIND = 30 Kph) SIMILAR SETTINGS: DOSAGE (1.8 m / 8 hr)

For the 30 Kph case, the reported VLSTRACK area (0.47 Km^2) is 2.2 times the size of the HPAC AMD estimated area (0.21 Km^2). The reported VLSTRACK area is 4 percent larger than the HPAC mean area (0.45 Km^2). Both models predict areas that are less than 1 Km^2.

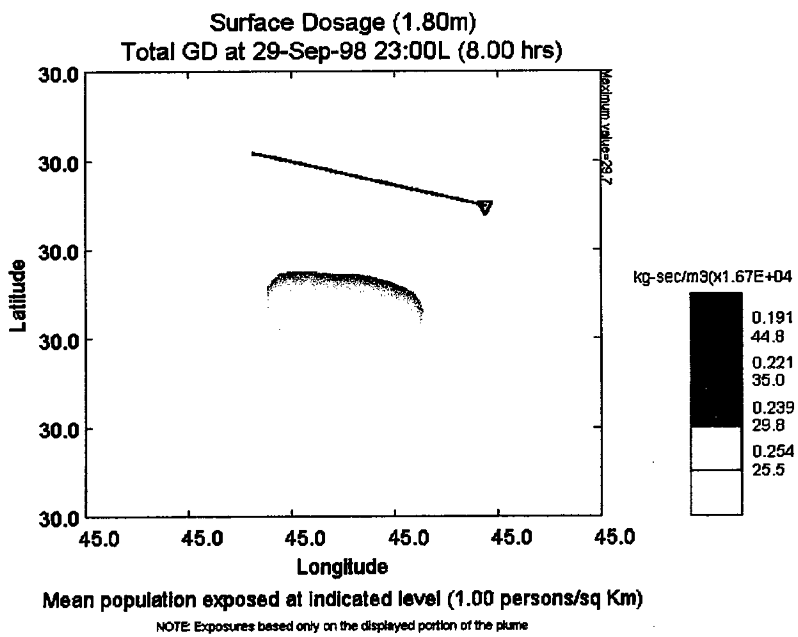
1,000 Kg GD (Soman) From Sprayer at 100 m AGL (800 m Line) (Fixed Wind = 30 Kph) Similar Settings: Dosage (1.8 m / 8 hr)

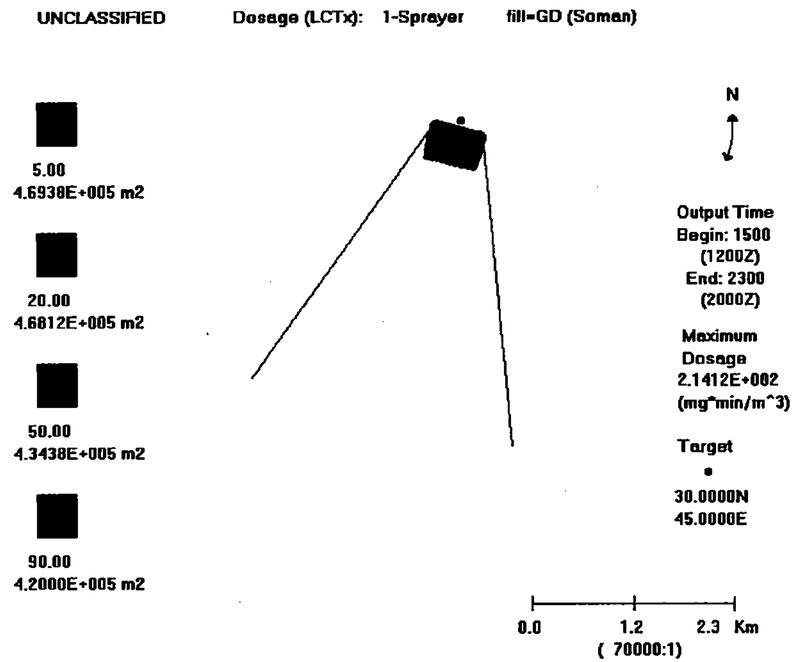
HPAC

VLSTRACK

Different scales shown

L*W = 0.58 * 0.47





At "LCt5"
Estimated Area (Km²)

HPAC [Mean Area]
0.21 [0.45]

VLSTRACK {measured}
0.47 {0.29}

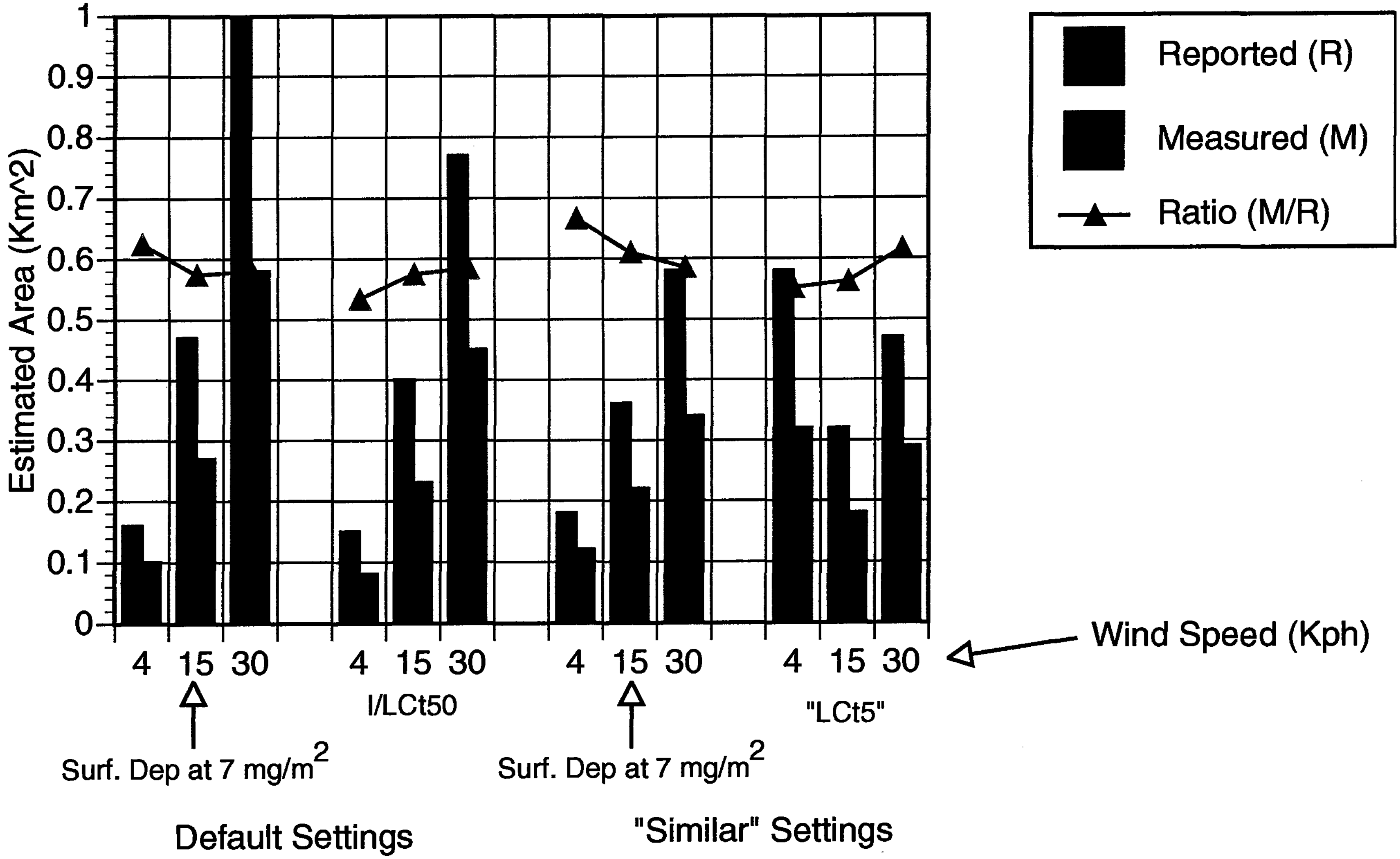
REPORTED VS. MEASURED VALUES FOR VLSTRACK OUTPUT

The next 13 slides provide an analysis of the GD sprayer trials.

The chart opposite compares the VLSTRACK reported and measured area sizes (in Km^2) or surface deposition and dosage. The reported VLSTRACK value appears to the left of the typical VLSTRACK output for each specified contour level. For this analysis, we have assumed that this number corresponds to a mean or expected value as predicted by VLSTRACK. The measured value is estimated by measuring the length and width of the displayed graphic and computing the area of the enclosed ellipse or rectangle. As we have noted earlier, the values obtained in this way differ and the VLSTRACK developers are aware of this "plotting/display" problem. The developers plan to fix this problem in VLSTRACK 3.0. We note, however, that users of 1.6.3 will obtain graphical output and numerical output that differ.

The accompanying chart shows, that for all cases examined, the ratio of measured to reported area size is about 0.60. In fact, the average ratio is 0.585. To first order, we can imagine correcting the measured areas by multiplying them by 1.709 (= 1/0.585). Assuming that the plotting errors are isotropic – equal in all directions – linear measures (e.g., distance traveled) can be corrected by multiplying by the square root of 1.709 – 1.307. This factor is used in order to arrive at comparable distances traveled by the cloud center. For example, see page B-8 of this document.

Reported vs. Measured Values for VLSTRACK Output



HPAC / VLSTRACK SPRAYER COMPARISONS OF DOSAGE: DEFAULT VS. "SIMILAR"

The accompanying chart compares the areas predicted by HPAC and VLSTRACK for the 8-hour dosages. The figure compares those GD sprayer trials done with default and similar settings for all three wind speeds that were examined. Both the HPAC AMD and mean area values are compared to the VLSTRACK predictions. The red triangles on the figure correspond to the percent difference between the given predictions. This percent difference was calculated by dividing the absolute difference between the predictions by the larger of the two area predictions.

For the default trials, the dosages at the HPAC-defined incapacitation 5 percent (ICt5) level are compared to the VLSTRACK LCt50 since both assume 35 mg-min/m^3. **It is important to note that a typical user may be unaware of the differences in effects assumptions between HPAC and VLSTRACK. These differences alone could lead to very "different" predictions by the two models.**

For the similar trials, the effects assumptions are the same. Therefore, for the similar trials, the figure compares the LCt5 level for both HPAC and VLSTRACK.

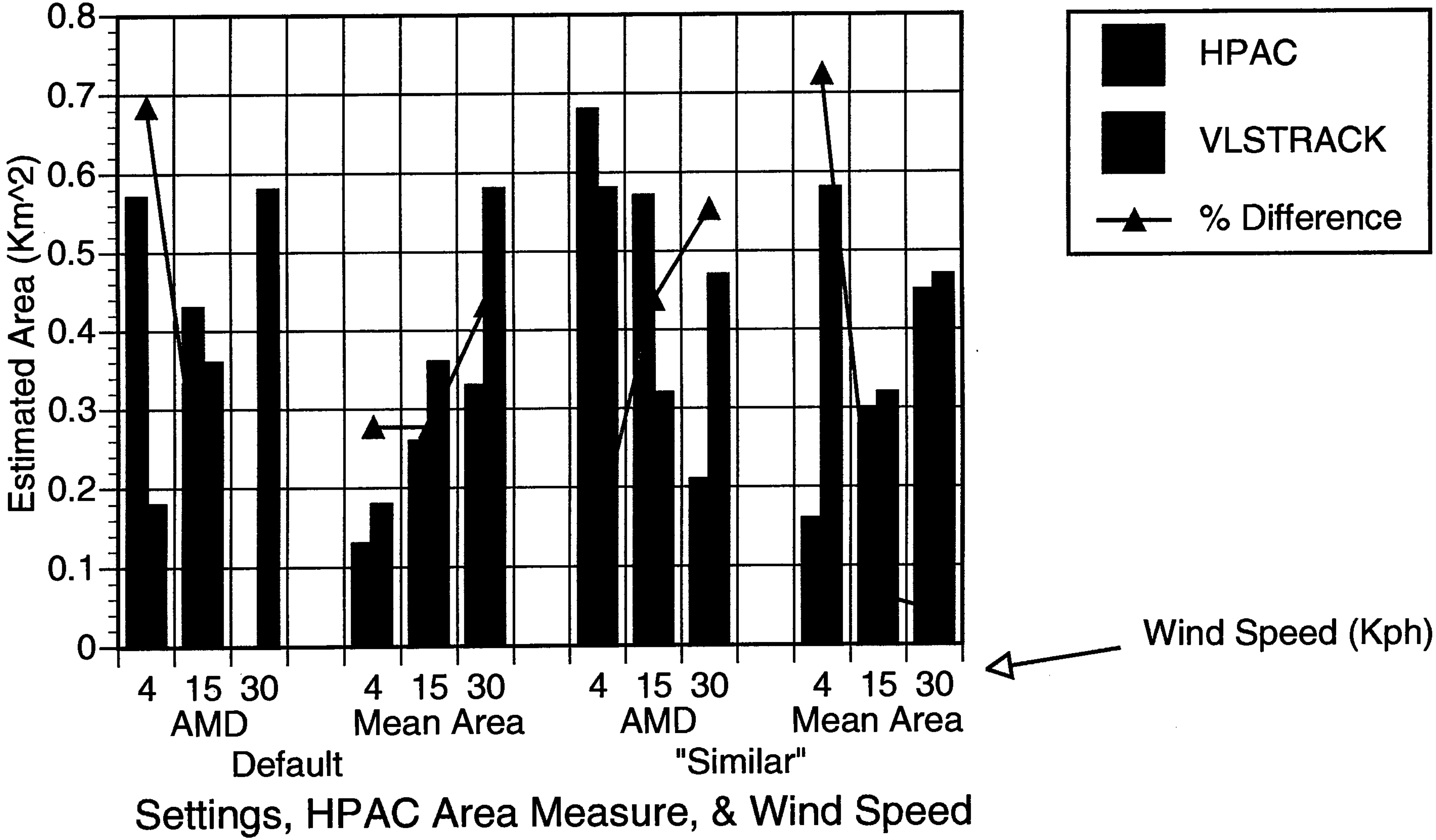
All of the dosage prediction areas shown in the accompanying chart are less than 0.70 Km^2. For many operational situations, these model predictions would be considered quite similar.

Considering the details of the HPAC AMD comparisons, we note that the percent difference is greatly reduced for the 4 and 30 Kph trials when the similar settings were used (relative to the default settings).[34] For the HPAC mean area comparisons to VLSTRACK, percent differences associated with the 15 and 30 Kph were lowered when the similar settings were used.

These comparisons suggest that for this scenario – GD sprayer with fixed winds – and even after properly accounting for the effects assumptions, the variance differences between the dosage predictions of the two models can be somewhat minimized by standardizing the source terms and meteorological input, where possible. Recall that in creating the similar settings from the default settings, we adjusted the initial lateral sigma, mass median drop diameter and distribution sigma, and the wind measurement height so that they would be identical for each model.

34 The percent difference for the default, HPAC AMD, 30 Kph comparison is essentially infinite since the predicted HPAC AMD value was 0.0.

HPAC / VLSTRACK Sprayer Comparisons of Dosage: Default vs. "Similar"



HPAC RESULTS WITH CONDITIONAL AVERAGING = 0: DEPOSITION

The chart opposite presents the HPAC predictions for surface deposition that result from setting the conditional averaging (T_{avg}) equal to zero. It is not expected that typical HPAC operational users will access the advanced editor in order to adjust this fundamental transport and dispersion parameter. Rather, it is expected that the typical user will rely on HPAC's chosen default for this parameter. For this study, we set $T_{avg} = 0$ in order to examine the causes of differences between HPAC and VLSTRACK that had been observed.

T_{avg} is the averaging time for defining the diffusive component of turbulence. This parameter is used to scale the velocity variances that determine puff diffusion. A quasi-deterministic prediction of dispersion can be obtained by neglecting the "meandering" component of turbulence (length scales greater than the plume or cloud size). For this usage, T_{avg} should be set to the smaller of the release duration and the sampling period of interest. The HPAC default setting for T_{avg} uses the full spectrum of turbulence (low to high frequency) for the diffusion calculation (equivalent to a very large T_{avg}).[35]

The accompanying chart presents the HPAC surface deposition predictions at 2 minutes and 4 hours for the three fixed wind cases that were examined. Next to each figure, the length (L), width (W), estimated AMD area (A), and the mean area (in red), all at LD2, are shown. All of these runs were done with the "similar settings" assumptions.

In all cases, the AMD values are somewhat larger for the default settings of T_{avg} (relative to the AMD values predicted with $T_{avg} = 0$). In contrast, the mean values are significantly smaller for the default setting of T_{avg}.

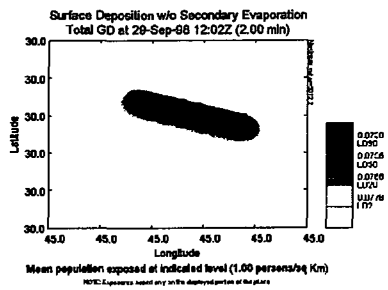
Most of the surface deposition occurs quickly (within minutes). The removal of the lower frequency component of the turbulence appears to have shortened the tail of the distribution from which AMD is computed. In the case of the mean area, we speculate that the many grid points that led to very low levels, due to many realizations in which the deposition at that grid value was zero (i.e., an intermittent distribution), were reduced by the elimination of the meandering (low frequency) turbulence component. Given an intermittent distribution, the HPAC-predicted mean area may correspond to the more appropriate value for presentation to the user.

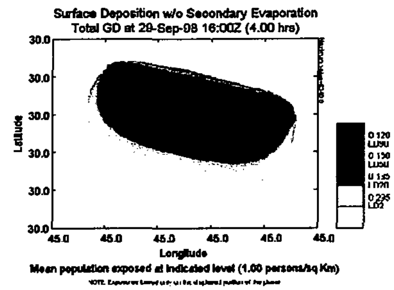
---

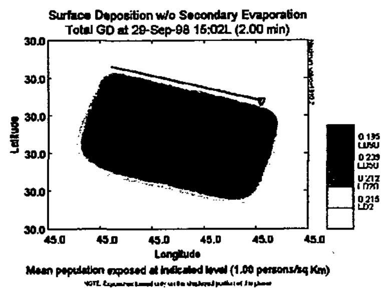
35 A description of this usage of the conditional averaging toggle was extracted from the HPAC 3.1 help feature.

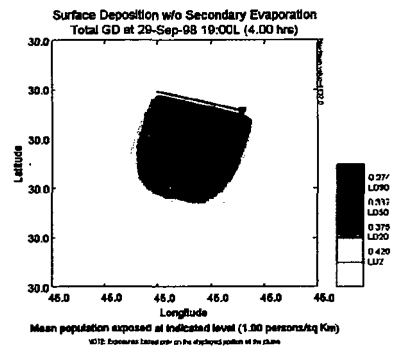
HPAC Results With Conditional Averaging = 0: Deposition

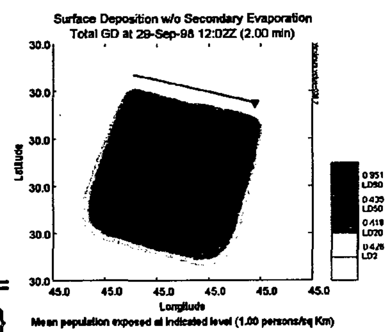
	2 min	4 hr
4 Kph	L,W,A{Mean Area} = 0.23,1.03,**0.19**{0.08}	L,W,A{Mean Area} = 0.81,1.06,**0.68**{0.32}
15 Kph	L,W,A{Mean Area} = 0.62,1.00,**0.49**{0.22}	L,W,A{Mean Area} = 0.93,0.85,**0.62**{0.48}
30 Kph	L,W,A{Mean Area} = 1.13,0.99,**1.12**{0.43}	L,W,A{Mean Area} = 2.46,1.05,**2.02**{0.84}

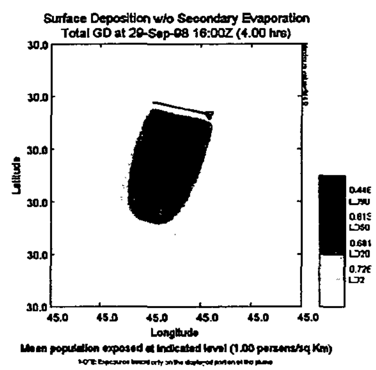












HPAC RESULTS WITH CONDITIONAL AVERAGING = 0: CONCENTRATION

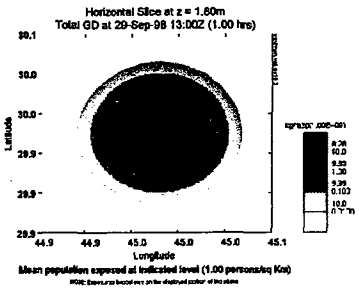
The chart opposite presents the HPAC predictions for concentration (at 1.8 m) that result from setting the conditional averaging (T_{avg}) equal to zero. The numerical values shown for L, W, A, and mean area correspond to the 0.01 μg/m^3 contour. All of these runs were done with the "similar settings" assumptions.

In general, the predicted values are somewhat smaller than those predicted with the default settings of T_{avg}. The exceptions are the AMD at 4 hours and with a wind speed of 30 Kph (1,303 vs. 1,324 Km^2) and the mean area at 4 hours with a wind a speed of 15 Kph (86 vs. 121 Km^2).

HPAC Results With Conditional Averaging = 0: Concentration

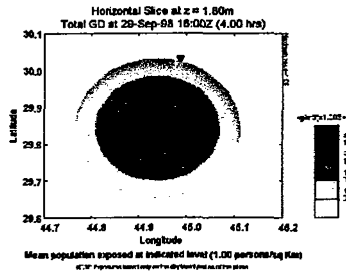
	1 hr		4 hr

4 Kph

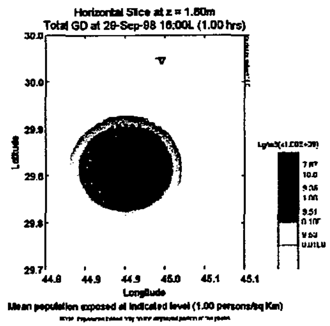


L,W,A{Mean Area} =
15.1,14.9,**177**{10}

L,W,A{Mean Area} =
38.1,37.8,**1133**{121}

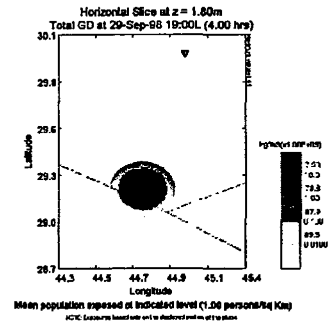


15 Kph

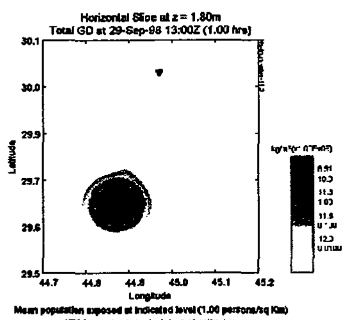


L,W,A{Mean Area} =
16.8,15.6,**205**{10}

L,W,A{Mean Area} =
37.1,38.0,**1107**{90}

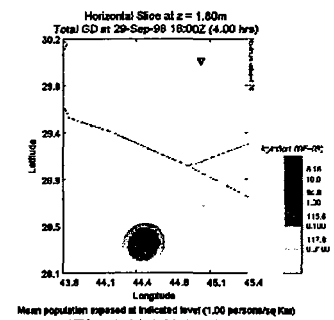


30 Kph



L,W,A{Mean Area} =
18.6,16.5,**242**{12}

L,W,A{Mean Area} =
45.2,37.3,**1324**{118}



HPAC RESULTS WITH CONDITIONAL AVERAGING = 0: DOSAGE

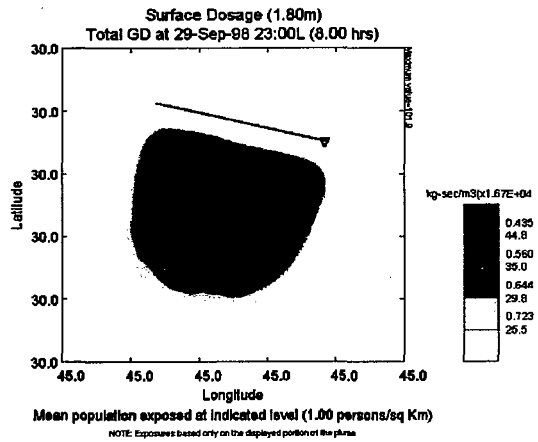
The accompanying chart presents the HPAC predictions for dosage (at 1.8 m) that result from setting the conditional averaging (T_{avg}) equal to zero. The numerical values shown correspond to the "LCt5" level – 25.527 mg-min/m^3. All of these runs were done with the "similar settings" assumptions.

In general, the predicted values are somewhat larger than those predicted with the default settings of T_{avg}. The exception is the AMD with a wind speed of 4 Kph (0.68 vs. 0.59 Km^2).

HPAC Results With Conditional Averaging = 0: Dosage (8 hr)

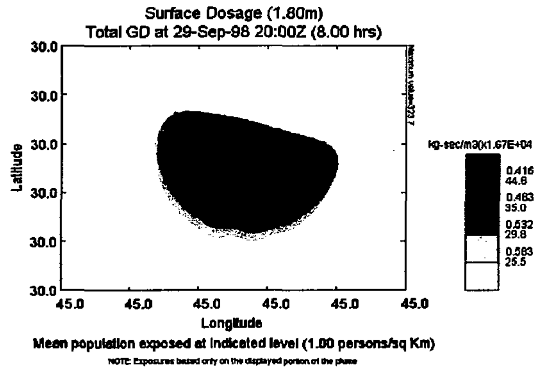
15 Kph

L,W,A{Mean Area} =
0.93,0.85,**0.62**{0.76}



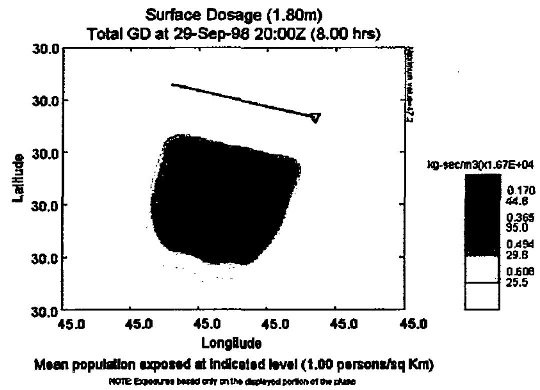
4 Kph

L,W,A{Mean Area} =
0.78,0.97,**0.59**{0.59}



30 Kph

L,W,A{Mean Area} =
0.86,0.77,**0.52**{0.64}



AREA OF THE MEAN DOSAGE VS. MEAN AREA VALUES FOR HPAC AT "LCt5"

The chart opposite provides a comparison of the HPAC dosage areas computed in two different ways – AMD and mean area. It is apparent that when T_{avg} is set at 0.0, thus removing the low frequency (meandering) component of the turbulence, the two different HPAC-predicted areas are in good agreement (within about 20 percent in all cases).

The mean area values increase significantly when T_{avg} is set at 0.0. The suggestion is that the intermittent nature of the spatial distribution (d{x,y}) that arises when the low frequency turbulence component is "turned on" leads to smaller areas containing the specified dosage and hence a smaller predicted mean area. This effect is particularly significant at the slower wind speeds (e.g., 4 Kph). The area of the mean dosage, based on dbar{x,y}, is only marginally affected at the slower speeds (4 and 15 Kph).

Both measures correspond to expected values and the variance associated with them depends, in part, on the shape of the distribution from which they arise. **These values do not necessarily correspond to the area size that HPAC would predict is realized half the time. In fact, it is feasible that these values could be quite different from the 50th percentile value.**

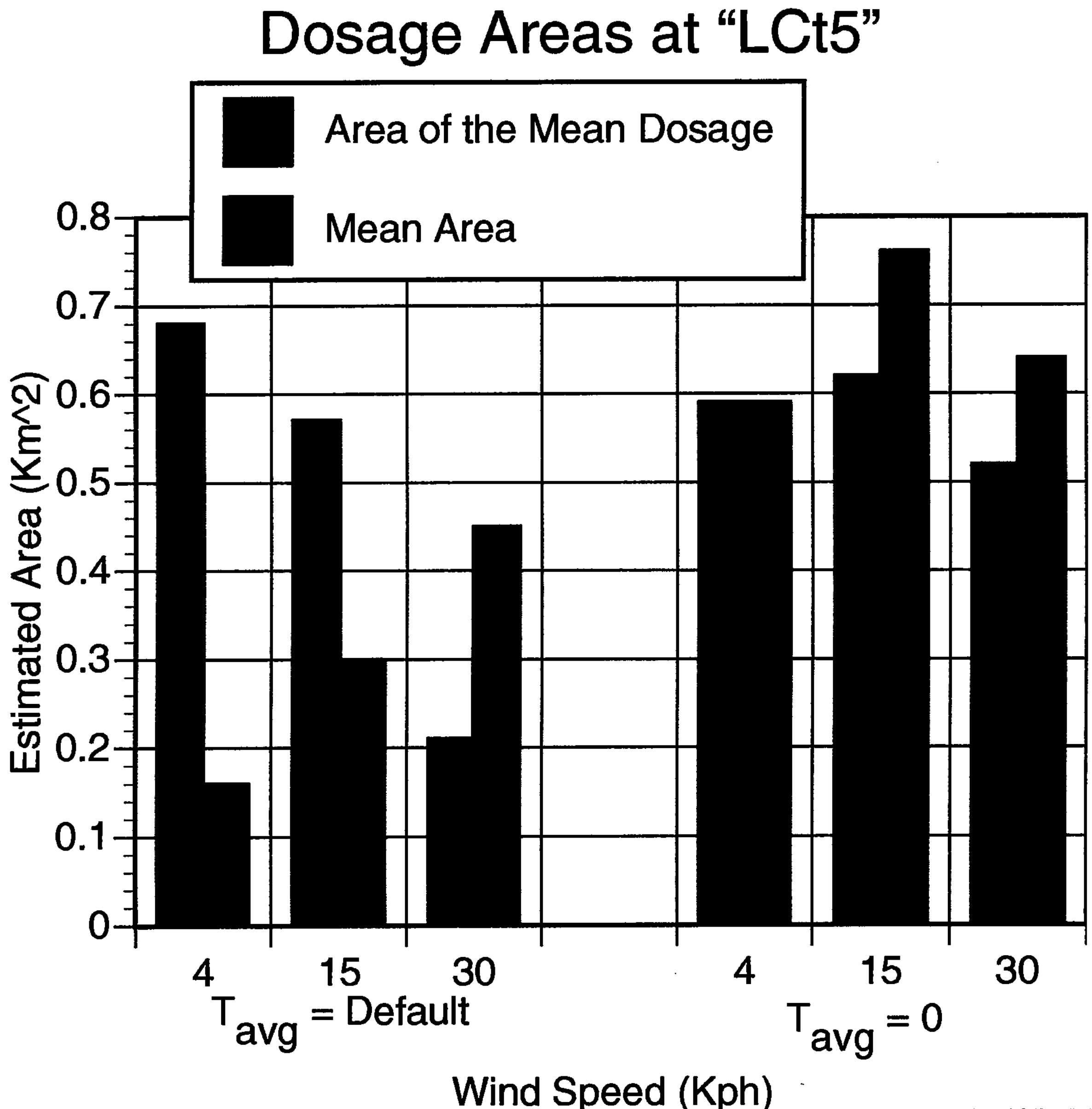
It may be true that presenting HPAC predictions in terms of percentiles represents an improved method of communication to the operational user. For example, in some cases, the area in which a particular probability of achieving a given threshold is presented may have greater operational utility (perhaps based on the distribution of areas computed from individual dosage fields, d{x,y}).

The above philosophy appears to take advantage of one of HPAC's reported strengths – its ability to estimate the concentration fluctuation variance[36] – and should be, at least in part, a motivating factor for the inclusion of the HPAC "Hazard Area" feature in 3.0 and later versions.[37]

36 *Second Order Closure Integrated PUFF (SCIPUFF) Model Verification and Evaluation Study*, Atmospheric Turbulence and Diffusion Division, Air Resources Laboratory, National Oceanic and Atmospheric Administration (NOAA), May 1998, page 6.

37 *HPAC Version 3.0 Manual*, Defense Special Weapons Agency, 1997, page 11.

Area of the Mean Dosage vs. Mean Area Values for HPAC at "LCt5"



VLSTRACK WITH PASQUILL STABILITY (PS) CATEGORY SET AT VERY UNSTABLE (A)

As a part of the meteorology input window associated with VLSTRACK, the parameter "Pasquill Stability Category" is presented. The Pasquill stability (PS) categories – very unstable (A), unstable (B), slightly unstable (C), neutral (D), slightly stable (E), stable (F), and very stable (G) – are meant to characterize the atmospheric stability below the mixing layer.[38] A stability category can basically be specified in terms of wind speed and the vertical flux of sensible heat. Since the latter parameter may not typically be available, specifying the stability category in terms of incoming solar radiation or, as a further simplification, in terms of insolation and cloud cover is useful.[39]

To this point, we have presented results based only on the selection of the "determined by program" default VLSTRACK value. Since the PS categories appeared relatively assessable by the user, we examined the effect of setting the category at its most unstable value. **Our motivation was to examine whether changes in the PS value would lead to much larger areas of low-level (0.01 μg/m^3) concentration.**

The chart opposite presents the predicted surface deposition, concentration, and dosage for the 4 and 30 Kph fixed wind GD sprayer cases when the PS category was set at A.[40]

For the default and similar trials that were previously described, the initial (first time period) PS categories chosen by VLSTRACK were B, C, and D for the 4, 15, and 30 Kph cases, respectively. The deposition areas predicted at PS = A, are larger (at 7 mg/m^2) by 47, 58, and 60 percent than the corresponding default PS settings 4, 15, and 30 Kph cases, respectively. The dosage areas predicted at PS = A, are larger (at LCt5) by 16 and 2 percent, for the 15 and 30 Kph cases, and smaller by 16 percent for the 4 Kph relative to the corresponding default PS settings trials. The predicted concentrations (at 1 and 4 hours and at 0.01 μg/m^3) are significantly larger in all cases when PS is set at A.

38 *Software User's Manual for the Chemical/Biological Agent Vapor, Liquid, and Solid Tracking (VLSTRACK) Computer Model, Version 1.6.3 (Windows)*, Naval Surface Warfare Center, Dahlgren Division, Dahlgren, VA, September 1997, page 4-30.

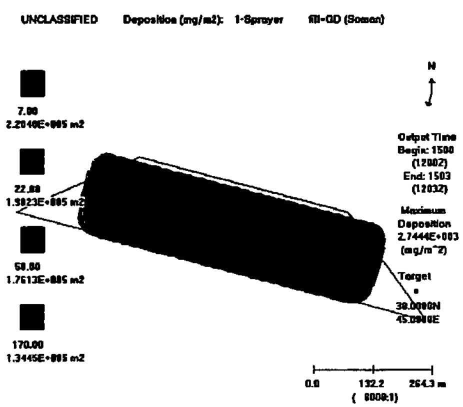
39 *Atmospheric Diffusion*, F. Pasquill, 2nd Edition, John Wiley & sons, 1974, page 374.

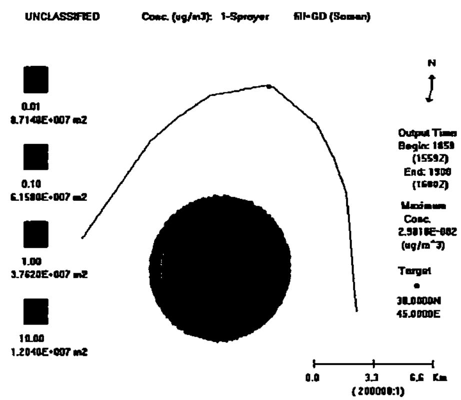
40 We have previously investigated the effect of setting PS = G for these particular sprayer trials with consistent results. *Interim Phase I Results of IDA's NBC Hazard Prediction M&S Task*, 14 October 1998.

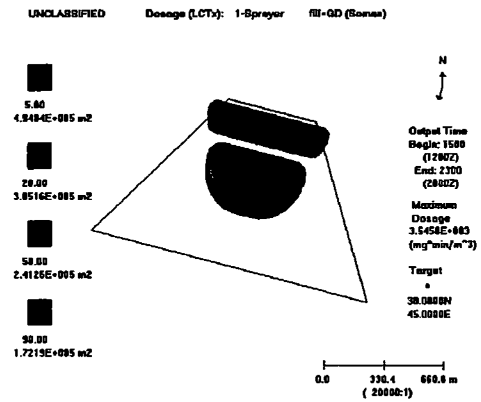
VLSTRACK With Pasquill Stability (PS) Category Set at Very Unstable (A)

	Surface Deposition (3 min)	Concentration (1.8 m / 4 hr)	Dosage (1.8 m / 8 hr)

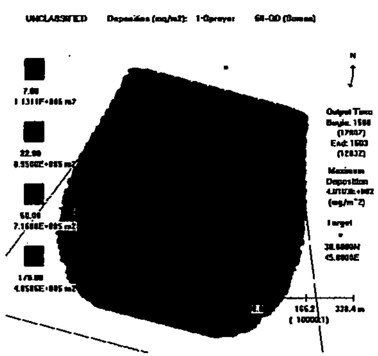
4 Kph

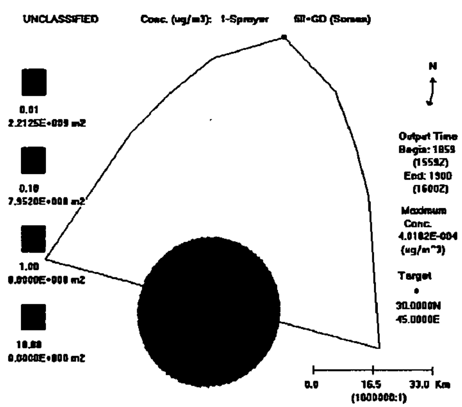


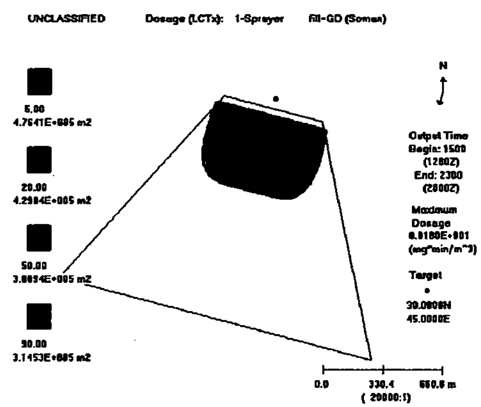




30 Kph







HPAC (AMD) / VLSTRACK SPRAYER COMPARISONS

The accompanying tables summarize the various GD sprayer comparisons that we have examined. The HPAC AMD values are compared to the reported VLSTRACK areas for each wind speed. Predicted surface deposition, concentration (at 1.8 m), and dosage (at 1.8 m) are shown (first column). The second column (text in italics) provides the default settings comparisons and the third column lists the similar settings comparisons. The fourth column (text in bold) provides the similar settings comparisons with the HPAC conditional averaging set at zero. The final column summarizes the similar settings comparisons with the VLSTRACK predictions done with PS = A.

HPAC (AMD) / VLSTRACK Sprayer Comparisons

At 15 Kph	Default		Similar		Similar + $T_{avg} = 0$		Similar + PS = A	
Parameter (in Km^2)	HPAC	VLST	HPAC	VLST	HPAC	VLST	HPAC	VLST
Deposition at 7 mg/m^2								
≈ 2 minutes	0.83	0.47	0.83	0.40	0.49	0.40	0.83	0.63
4 hours	1.79	na	1.79	na	0.62	na	1.79	na
Concentration at 0.01 $\mu g/m^3$								
1 hour	284	103	284	58	205	58	284	219
4 hours	1,254	347	1,254	193	1,107	193	1,254	475
Dosage at "LCt5"								
8 hours	0.43	0.36	0.57	0.32	0.62	0.32	0.57	0.37

At 4 Kph	Default		Similar		Similar + $T_{avg} = 0$		Similar + PS = A	
Parameter (in Km^2)	HPAC	VLST	HPAC	VLST	HPAC	VLST	HPAC	VLST
Deposition at 7 mg/m^2								
≈ 2 minutes	0.71	0.16	0.71	0.15	0.19	0.15	0.71	0.22
4 hours	1.40	na	1.40	na	0.68	na	1.40	na
Concentration at 0.01 $\mu g/m^3$								
1 hour	258	25	258	15	177	15	258	25
4 hours	1,175	62	1,175	37	1,133	37	1,175	87
Dosage at "LCt5"								
8 hours	0.57	0.18	0.68	0.58	0.59	0.58	0.68	0.49

At 30 Kph	Default		Similar		Similar + $T_{avg} = 0$		Similar + PS = A	
Parameter (in Km^2)	HPAC	VLST	HPAC	VLST	HPAC	VLST	HPAC	VLST
Deposition at 7 mg/m^2								
≈ 2 minutes	1.65	1.00	1.65	0.77	1.12	0.77	1.65	1.13
4 hours	2.69	na	2.69	na	2.02	na	2.69	na
Concentration at 0.01 $\mu g/m^3$								
1 hour	288	156	288	83	242	83	288	685
4 hours	1,303	808	1,303	423	1,324	423	1,303	2,213
Dosage at "LCt5"								
8 hours	0	0.58	0.21	0.47	0.52	0.47	0.21	0.48

HPAC (MEAN AREA) / VLSTRACK SPRAYER COMPARISONS

The tables opposite summarize our comparisons of HPAC mean area values and reported VLSTRACK predictions.

HPAC (Mean Area) / VLSTRACK Sprayer Comparisons

At 15 Kph	Default		Similar		Similar + $T_{avg} = 0$		Similar + PS = A	
Parameter (in Km^2)	*HPAC*	*VLST*	HPAC	VLST	**HPAC**	**VLST**	***HPAC***	***VLST***
Deposition at 7 mg/m^2								
≈ 2 minutes	*0.03*	*0.47*	0.03	0.40	**0.22**	**0.40**	***0.03***	***0.63***
4 hours	*0.09*	*na*	0.09	na	**0.48**	**na**	***0.09***	***na***
Concentration at 0.01 $\mu g/m^3$								
1 hour	*14*	*103*	14	58	**10**	**58**	***14***	***219***
4 hours	*131*	*347*	131	193	**90**	**193**	***131***	***475***
Dosage at "LCt5"								
8 hours	*0.26*	*0.36*	0.30	0.32	**0.76**	**0.32**	***0.30***	***0.37***

At 4 Kph	Default		Similar		Similar + $T_{avg} = 0$		Similar + PS = A	
Parameter (in Km^2)	*HPAC*	*VLST*	HPAC	VLST	**HPAC**	**VLST**	***HPAC***	***VLST***
Deposition at 7 mg/m^2								
≈ 2 minutes	*0.01*	*0.16*	0.01	0.15	**0.08**	**0.15**	***0.01***	***0.22***
4 hours	*0.04*	*na*	0.04	na	**0.32**	**na**	***0.04***	***na***
Concentration at 0.01 $\mu g/m^3$								
1 hour	*10*	*25*	10	15	**10**	**15**	***10***	***25***
4 hours	*86*	*62*	86	37	**121**	**37**	***86***	***87***
Dosage at "LCt5"								
8 hours	*0.13*	*0.18*	0.16	0.58	**0.59**	**0.58**	***0.16***	***0.49***

At 30 Kph	Default		Similar		Similar + $T_{avg} = 0$		Similar + PS = A	
Parameter (in Km^2)	*HPAC*	*VLST*	HPAC	VLST	**HPAC**	**VLST**	***HPAC***	***VLST***
Deposition at 7 mg/m^2								
≈ 2 minutes	*0.08*	*1.00*	0.08	0.77	**0.43**	**0.77**	***0.08***	***1.13***
4 hours	*0.19*	*na*	0.19	na	**0.84**	**na**	***0.19***	***na***
Concentration at 0.01 $\mu g/m^3$								
1 hour	*16*	*156*	16	83	**12**	**83**	***16***	***685***
4 hours	*148*	*808*	148	423	**118**	**423**	***148***	***2,213***
Dosage at "LCt5"								
8 hours	*0.33*	*0.58*	0.45	0.47	**0.64**	**0.47**	***0.45***	***0.48***

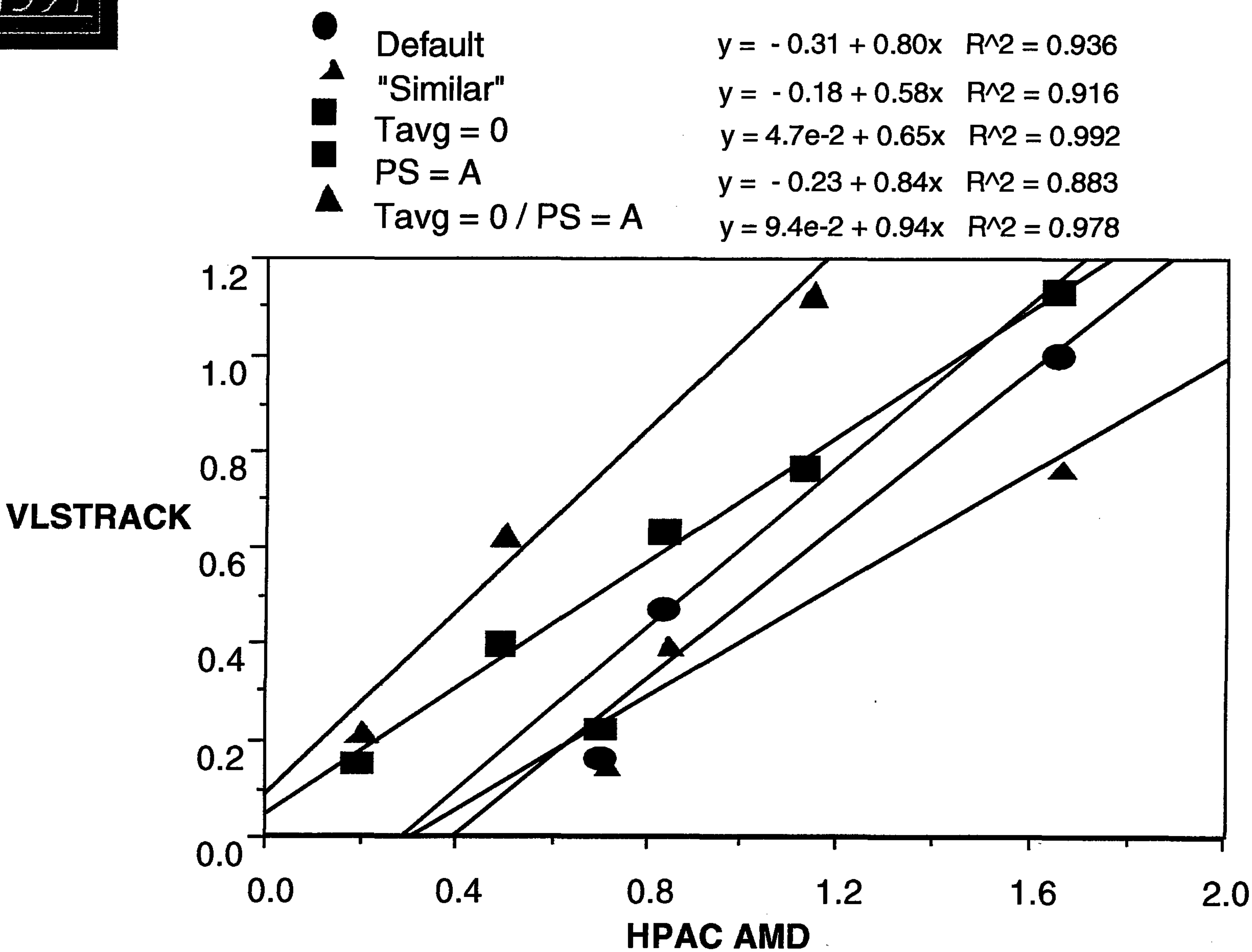
HPAC AMD VS. VLSTRACK: DEPOSITION AREA (Km^2) AT ≈ 2 min

The accompanying figure presents a scatter plot of the HPAC AMD and reported VLSTRACK value for surface deposition area at a contour level of 7 mg/m^2. The different colors of the symbols correspond to a different comparative condition. There are three points for each symbol type because each comparison was done at three wind speeds – 4, 15, and 30 Kph. The colored lines correspond to the "least-squares" linear fit to the three data points of each comparison. The linear equation of each line is reported to the right of the associated comparison. The light blue triangles, denoted as "$T_{avg} = 0$ / PS =A" in the key, correspond to the comparative case where the HPAC prediction was run with $T_{avg} = 0$ and the VLSTRACK prediction was run with PS = A.

If the HPAC AMD and VLSTRACK predictions were in perfect agreement, one would expect that the best linear fit would intercept the origin, have a slope of 1.0, and a coefficient of correlation (R^2) of 1.0. The equation that best meets these requirements is associated with the $T_{avg} = 0$ / PS = A comparison. The comparisons that include similar settings and $T_{avg} = 0$, the red squares and light blue triangles, appear to be represent the comparisons in which the HPAC AMD and VLSTRACK predictions for surface deposition are most similar.

The typical user might realize results that are consistent with the default settings comparisons. However, this scatter plot is consistent with the notion that the combination of standardizing the source term inputs and effects assumptions (7 mg/m^2) and ignoring the contribution of the low frequency turbulence component of HPAC can lead to quite similar surface deposition results for this particular case.

HPAC AMD vs. VLSTRACK: Deposition Area (Km^2) at ≈ 2 min



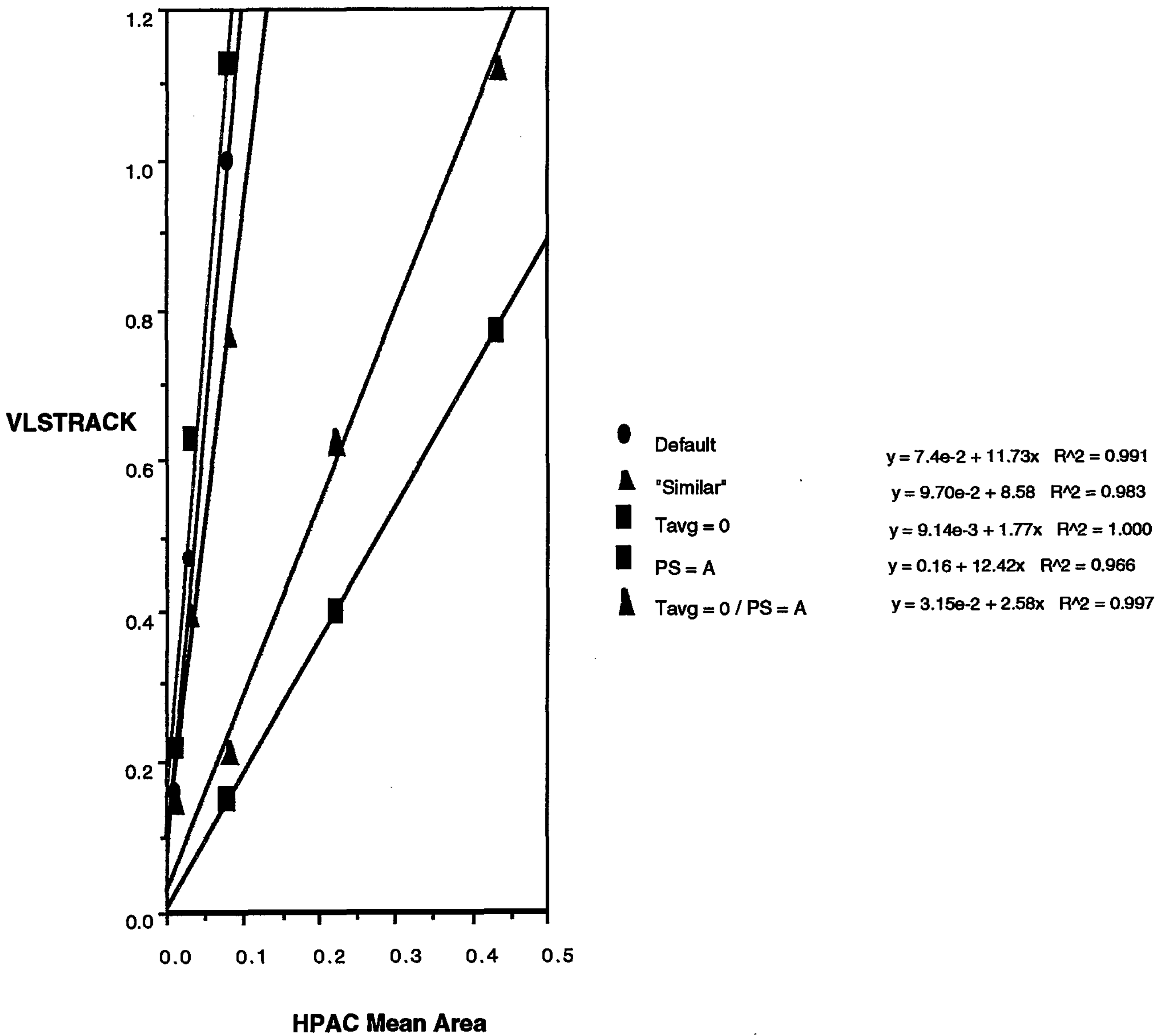
HPAC MEAN AREA VS. VLSTRACK: DEPOSITION AREA (Km^2) AT ≈ 2 min

The accompanying figure presents a scatter plot of the HPAC mean area and reported VLSTRACK value for surface deposition area at a contour level of 7 mg/m^2.

As was true when comparing HPAC AMD to the reported VLSTRACK value, the trials in which the HPAC conditional averaging was set at zero and the similar settings were used led to the most similar results. However, in this case – HPAC mean area vs. VLSTRACK – the slopes associated with the linear fits are too large. That is, the VLSTRACK predicted area (as can be seen in the previous tables) is significantly larger than the predicted HPAC mean area. This may suggest that, at least for surface deposition comparisons, the HPAC AMD values represent a more appropriate parameter for **technical comparison** to the reported VLSTRACK value than does the HPAC mean area. Of course, the most **meaningful operational comparison** probably arises from the default settings case.

A similar set of scatter plots was created using 8-hour dosage at 1.8 m as the predicted measure of interest. These plots were not particularly informative with comparisons of both HPAC AMD and HPAC mean area vs. VLSTRACK "performing" erratically.

HPAC Mean Area vs. VLSTRACK: Deposition Area (Km^2) at ≈ 2 min



COMPARATIVE OBSERVATIONS FROM ARTILLERY WITH GB TRIALS

The second set of comparative trials that we investigated considered artillery-delivered GB (Sarin). The next nine slides and nine text pages describe the results of this comparison.[41]

The default input values that were realized during our operation of the two models in this scenario differed in several ways. For instance, the two models differed in their default values for mass per round, rounds per fire, dissemination efficiency, and effects assumptions.

If one considers only lethal levels of deposition (via skin contact) and dosage (inhaled), then both models may be seen to provide similar predictions. Using the default settings or the "similar" settings, both models predicted lethal level deposition (LD2 – 180 mg/m^2) areas less than 0.05 Km^2. Similarly, both models predicted 5 percent lethal dosage areas (LCt5) of less than 0.3 Km^2. For many applications, these results might be considered equivalent.

Predictions of lower level concentrations and depositions were significantly different. For example, HPAC predicted lower level (0.1 mg/m^2) surface deposition to extend several Km downwind. VLSTRACK did not report this low-level downwind deposition.

For this particular trial, the two models were in reasonable agreement for the higher-levels (lethal) of deposition and dosage regardless of whether the default settings or similar settings were used.

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41 One of the nine slides, for illustrative purposes, presents the results from a trial in which HD (mustard) was delivered by artillery.

Comparative Observations From Artillery With GB Trials

- **Defaults are somewhat different**
  - Mass per round, number of rounds, dissemination efficiency, mass median drop diameter and distribution sigma, height of burst, assumed wind measurement height, and effects assumptions
- **Lethal level contours are of similar size**
  - Surface deposition (LD2) and dosage (LCt5) areas are < 0.3 Km^2 for both models
- **Low-level concentration and low-level surface deposition are significantly different**
  - HPAC area continues to grow after the initial "splat" and leads to much longer low-level trails than VLSTRACK

152mm ARTILLERY GB (SARIN) (FIXED WIND = 8 Kph) DEFAULT SETTINGS: SURFACE DEPOSITION

The chart opposite shows a comparison of the surface deposition predicted by HPAC 3.1 and VLSTRACK 1.6.3. This comparative scenario examined a 152mm artillery barrage that occurred at 0700 local time in South Korea, just north of Seoul. A fixed wind speed of 8 Kph out of the west-northwest was assumed and the environment was considered forested and overcast.

Where reasonable, model default parameters were used for this trial. Three potentially important differences in the VLSTRACK and HPAC default inputs for the 152mm artillery barrage are shown below.

- VLSTRACK assumes a mass per round of 4 Kg, HPAC assumes a mass of 2.6 Kg.
- VLSTRACK assumes a dissemination efficiency (DE) of 60 percent, HPAC assumes 100 percent.
- VLSTRACK assumes 300 rounds, HPAC assumes the artillery (battalion) attack consists of 75 rounds.

The HPAC figure (left-hand side figure) shows the 75 rounds assumed for the 152mm battalion fire HPAC option and the lethality level associated with this barrage. The right-hand side figure provides the VLSTRACK prediction for its assumed 300-round barrage. There are some differences in the default assumed round distributions; HPAC appears to arise from a uniform elliptical and VLSTRACK appears to arise from a Gaussian (bivariate normal). However, the overall areas of potential lethality are quite similar.

The HPAC estimated area presented in black corresponds to the area of the ellipse that one could draw around the outermost rounds shown in the HPAC plot. The number shown in red corresponds to the HPAC reported mean area at the LD2 (180 mg/m^2) level. This number (0.045) is in very good agreement (within 2 percent), in part serendipitously so, with the reported VLSTRACK value (0.046).[42]

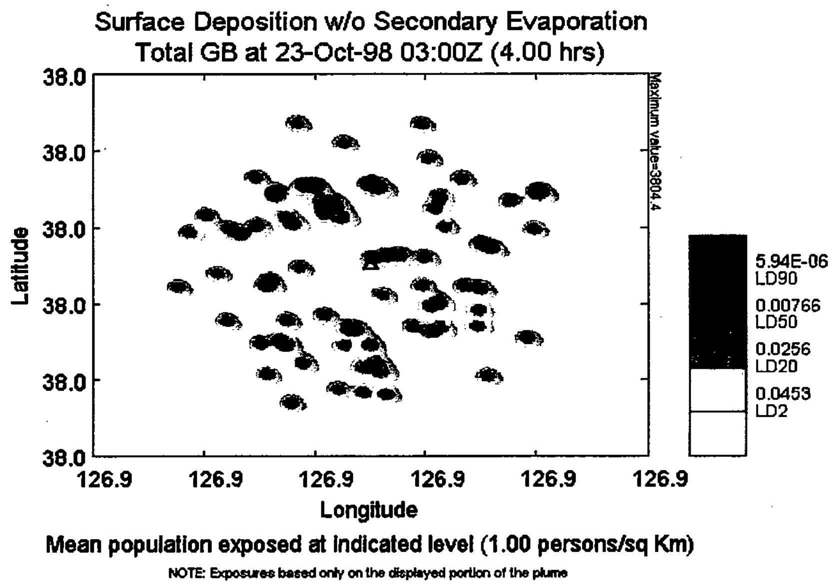
[42] For this VLSTRACK plot, we chose to display the contours at the four levels (in mg/m^2) that corresponded to the default HPAC percutaneous LDs (2, 20, 50, and 90) for an assumed exposed skin area of 1 m^2.

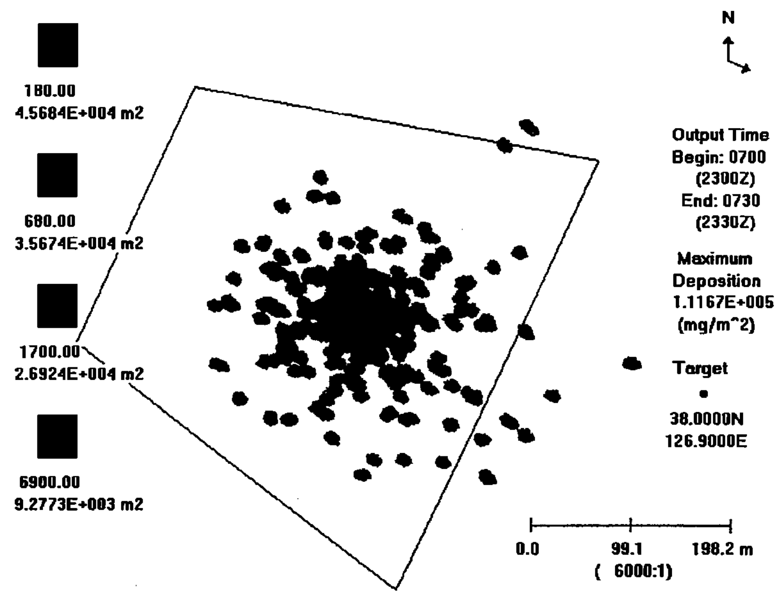
152mm Artillery GB (Sarin) (Fixed Wind = 8 Kph)
Default Settings: Surface Deposition

HPAC

VLSTRACK

Different scales shown





4 hour s
L*W =
0.53 * 0.49

At 180 mg/m² Estimated Area (Km²)	HPAC (4hr) [Mean Area]	VLSTRACK (30 m)
	0.20 [0.045]	0.046

152mm ARTILLERY GB (SARIN) (FIXED WIND = 8 Kph) DEFAULT SETTINGS: CONCENTRATION (1.8 m)

Comparisons of the 1- and 4-hour predicted concentrations, with the estimated area of the 0.01 $\mu g/m^3$ contour reported below, are shown to the right. The HPAC AMD values are significantly larger than the VLSTRACK reported value. The HPAC mean area values are significantly smaller than the VLSTRACK reported area. The shape differences of the presented contours, roughly circular versus elliptical, are reminiscent of our observations from the GD sprayer trial.

The gray area, shown on the HPAC plot and labeled "Dongducheon," corresponds to the more highly populated area associated with that South Korean city and is taken from the population database resident on the HPAC CD.

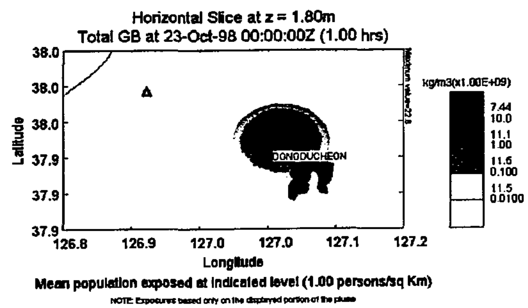
152mm Artillery GB (Sarin) (Fixed Wind = 8 Kph)
Default Settings: Concentration (1.8 m)

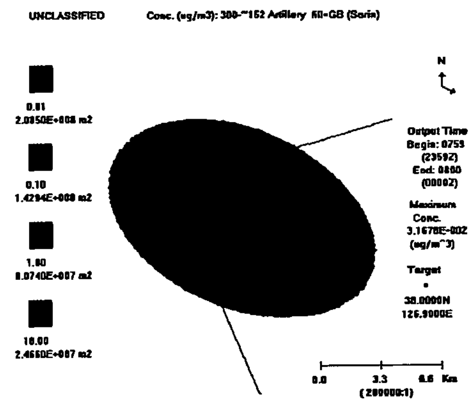
HPAC

VLSTRACK

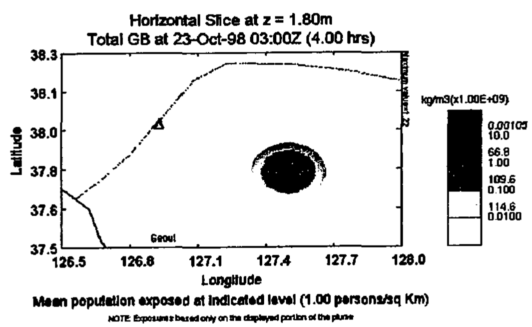
Different scales shown

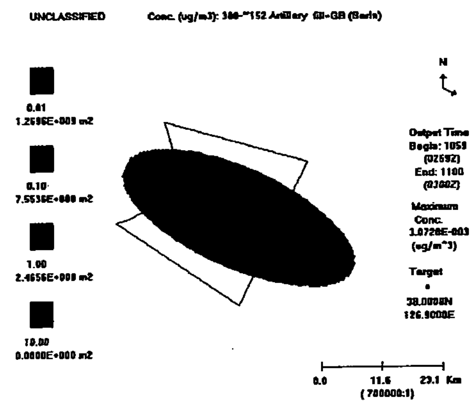
1 hour





4 hours





At 0.01mg/m³ (1 hr/4 hr) Estimated Area (Km²)	HPAC [Mean Area]	VLSTRACK
	65/693 [12/115]	209/1,270

152mm ARTILLERY GB (SARIN) (FIXED WIND = 8 Kph) DEFAULT SETTINGS: DOSAGE (1.8 m)

The accompanying chart provides a comparison of the default dosages presented by HPAC and VLSTRACK. HPAC provides a threshold value (assumed miosis), incapacitation concentrations (ICt5 and ICt50), and lethal concentrations (LCt50 and LCt90). VLSTRACK provides only lethal concentrations.

As was true for GD, the assumed HPAC ICt50 and VLSTRACK LCt50 dosages are identical, 35 mg-min/m^3. Therefore, for comparative purposes, we report the predicted areas of the HPAC ICt50 and VLSTRACK LCt50 contours.

The VLSTRACK reported area is somewhat larger than the HPAC area. However, both models predict dosage area less than 0.30 Km^2, probably considered identical for many operational applications.

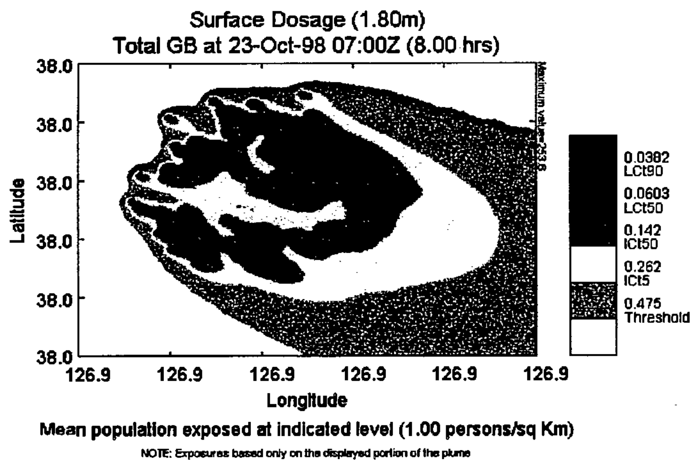
152mm Artillery GB (Sarin) (Fixed Wind = 8 Kph)
Default Settings: Dosage (1.8 m)

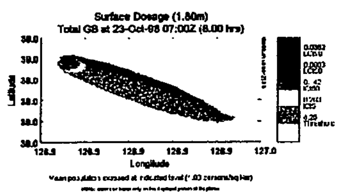
HPAC | VLSTRACK

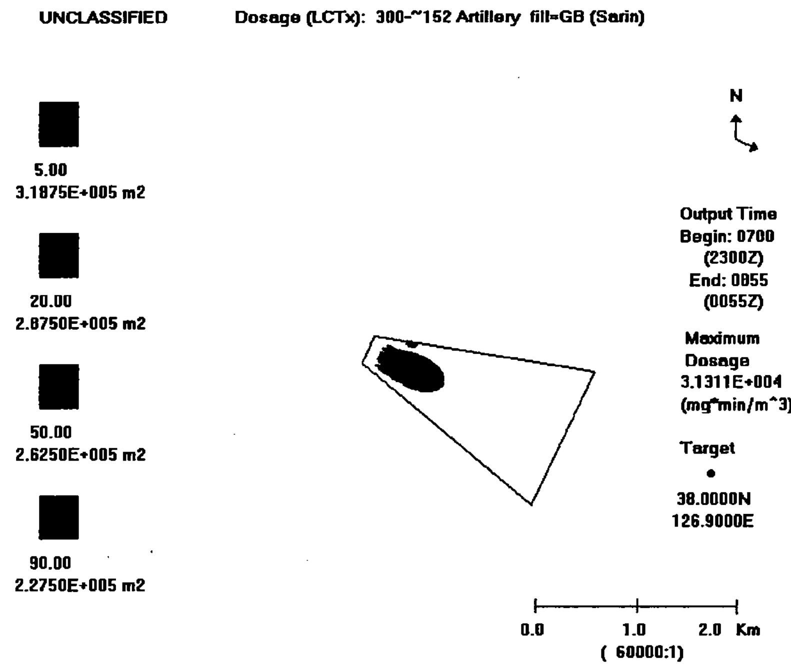
Different scales shown

8 hr | 2 hr

ICt50 L*W =
0.58 * 0.43







At I/LCt50 (35 mg-min/m³) Estimated Area (Km²)	HPAC [Mean Area]	VLSTRACK
	0.20 [0.14]	0.26

DEFAULT VS. "SIMILAR" SETTINGS FOR GB FROM 152mm ARTILLERY TRIALS

The accompanying table lists the changes that were made to these default trials in order to create as similar a set of initial conditions as possible – "similar" settings. Importantly, the mass per round, number of rounds, dissemination efficiency, assumed wind measurement height, and effects assumptions were set to be the same for each model.

Default vs. "Similar" Settings for GB from 152mm Artillery Trials

Model Parameter	*Default*		*"Similar"*	
	VLSTRACK	HPAC	VLSTRACK	HPAC
Mass (Kg)	4.0	2.6	4.0	4.0
Height of Release (m)	0	2	0	0
Lateral Sigma (m)	3	na	3	na
Vertical Sigma (m)	1.3	na	1.3	na
Initial Size (m)	na	6	na	3
# Submunitions	300	75	75	75
Dissemination Efficiency (%)	60	100	60	60
Mass Median Drop Diameter (μm)	150	200	200	200
Distribution Sigma (μm)	1.7	2	2	2
Wind Measurement Height (m)	2	10	10	10

Effects assumptions were set equal to the reported VLSTRACK values (mg-min/m^3):

LCt5 = 25.527
LCt20 = 29.781
LCt50 = 35.000
LCt90 = 44.757

152mm ARTILLERY GB (SARIN) (FIXED WIND = 8 Kph) SIMILAR SETTINGS: SURFACE DEPOSITION

The predictions for surface deposition are identical at the 180 mg/m^2 contour ("LD2") for each model. Recall that, for these artillery trials, the HPAC value reported in black corresponds to the measured area of the circle that contains all of the rounds. The cumulative area for all of the individual rounds is best represented by the reported HPAC mean area of the dose (0.016 Km^2).

152mm Artillery GB (Sarin) (Fixed Wind = 8 Kph)
Similar Settings: Surface Deposition

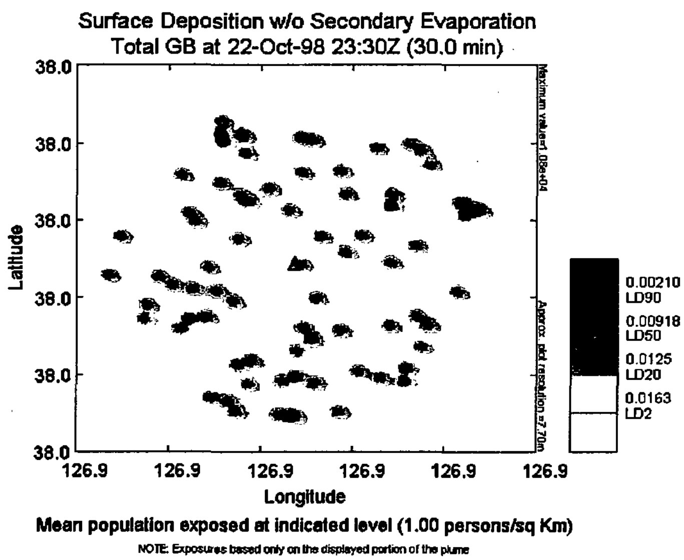
HPAC

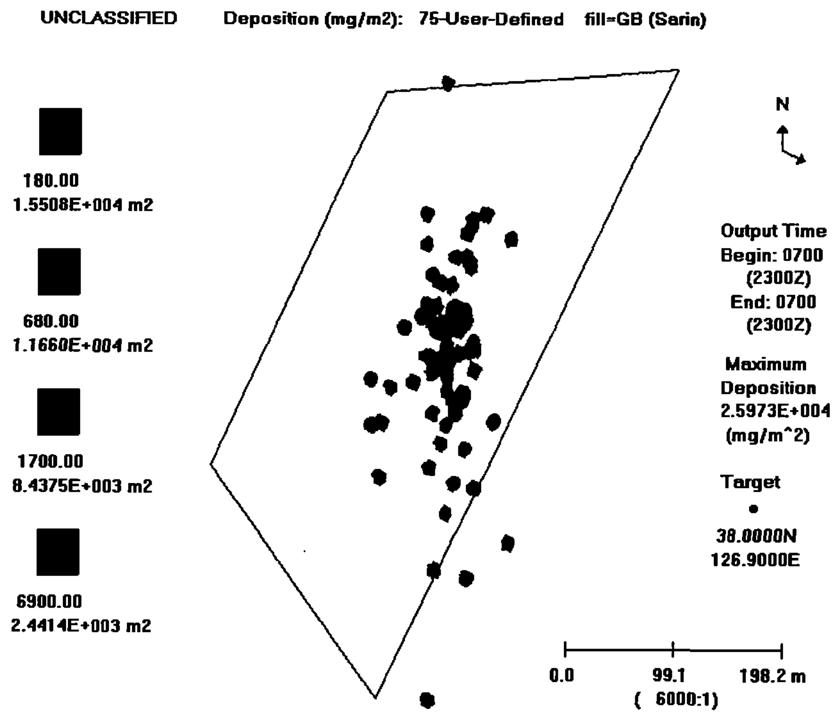
VLSTRACK

Different scales shown

30 minutes

L*W =
0.41 * 0.48





No change at 4 hours

At 180 mg/m² Estimated Area (Km²)	HPAC (30 min) [Mean Area]	VLSTRACK
	0.15 [0.016]	0.016

152mm ARTILLERY (100 ROUNDS WITH 2.6 Kg) GB (SARIN) (FIXED WIND): SURFACE DEPOSITION (1 & 30 min)

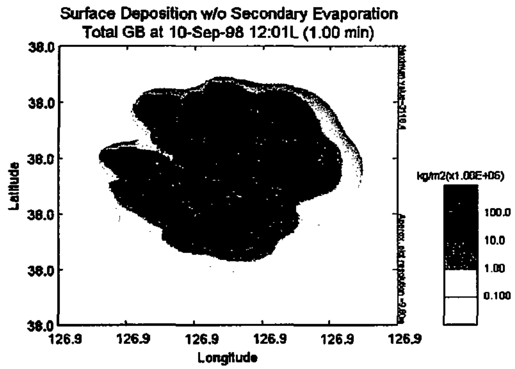
As an aside, we also examined a trial with slightly different, but roughly similar, settings and plotted lower-level surface deposition contours. The chart opposite presents a comparison with contours drawn down to 0.1 mg/m^2. This trial assumed 100 rounds, with 2.6 Kg per round, a dissemination efficiency of 100 percent, a burst height of 2 m, and a uniform elliptical initial artillery pattern for VLSTRACK.

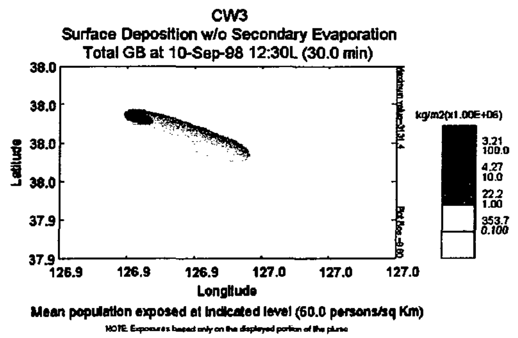
At 1-minute, the predictions of the two models are quite similar – surface deposition area at 0.1 mg/m^2 less than 0.5 Km^2. However, unlike the VLSTRACK prediction, HPAC reports a "downrange" hazard at low level. This same downrange low level deposition was observed for our nominal GB sprayer case (previous page).

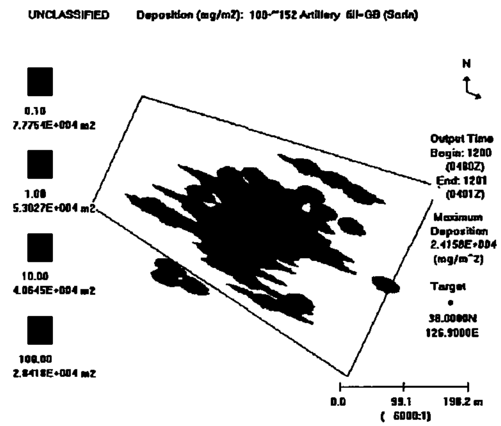
152mm Artillery (100 Rounds with 2.6 Kg) GB (Sarin) (Fixed Wind): Surface Deposition (1 & 30 min)

HPAC

VLSTRACK







Different scales shown

At 0.1 mg/m^2	HPAC 1 min/30 min	VLSTRACK
Length (Km)	0.77 /7	0.58
Width at Half Length (Km)	0.72 /2.5	0.37
Estimated Area (Km^2)	0.44/13.7	0.08

152mm ARTILLERY (100 ROUNDS WITH 2.6 Kg) HD (MUSTARD) (FIXED WIND): SURFACE DEPOSITION (1 hr)

A similar trial that considered mustard gas (HD) and the lowest available VLSTRACK contour (0.01 mg/m^2) is shown to the right. The predictions at low level are quite different. Again, the suggestion is that the low-level transport and dispersion, and hence surface deposition downrange, is handled differently by HPAC and VLSTRACK.

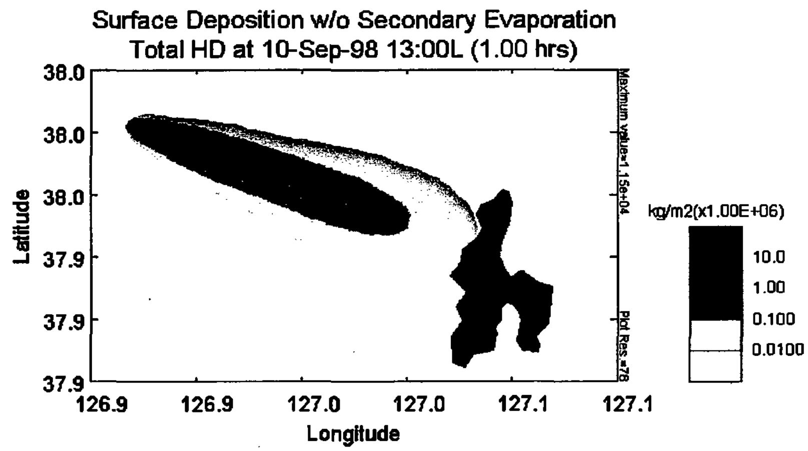
The gray area, shown on the HPAC plot, corresponds to the more highly populated area for this portion of South Korea.

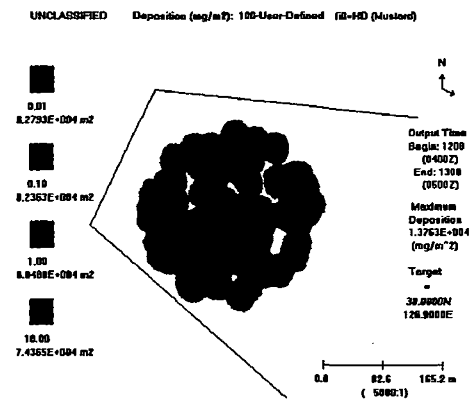
152mm Artillery (100 Rounds with 2.6 Kg) HD (Mustard) (Fixed Wind): Surface Deposition (1 hr)

HPAC

VLSTRACK

Different scales shown





At 0.1 mg/m^2	HPAC	VLSTRACK
Length (Km)	16	0.33
Width at Half Length (Km)	5	0.37
Estimated Area (Km^2)	63	0.08

152mm ARTILLERY GB (SARIN) (FIXED WIND = 8 Kph) SIMILAR SETTINGS: CONCENTRATION (1.8 m)

The chart opposite presents the 1- and 4-hour concentration predictions for the two models. The HPAC AMD areas, those corresponding to the displayed area are much larger than the VLSTRACK reported areas. The HPAC calculated mean area values are similar to the VLSTRACK reported areas.

This HPAC trial was rerun with $T_{avg} = 0$. For this trial, the predicted HPAC 1- and 4-hour 0.01 μg/m^3 contour areas were as follows:

- AMD = 59/640
- Mean Area = 10/98.

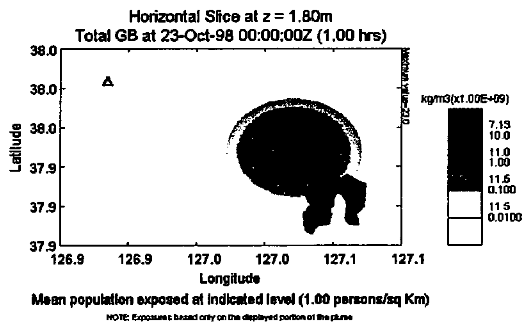
152mm Artillery GB (Sarin) (Fixed Wind = 8 Kph)
Similar Settings: Concentration (1.8 m)

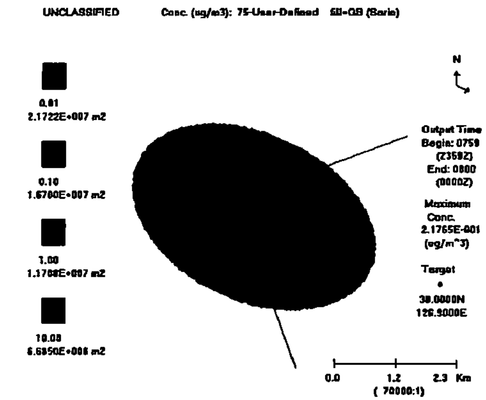
HPAC

VLSTRACK

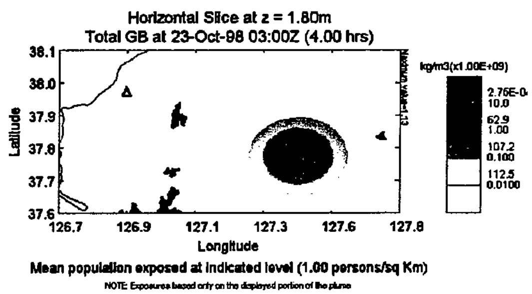
Different scales shown

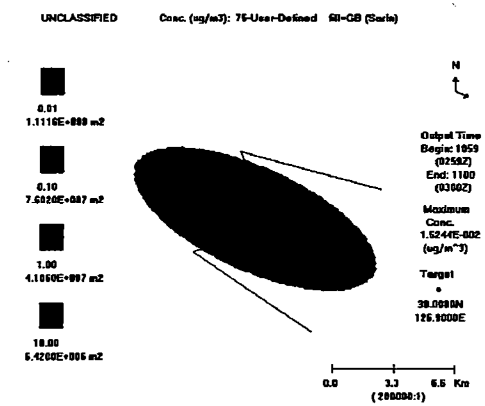
1 hour





4 hours





At 0.01mg/m^3 (1 hr/4 hr) Estimated Area (Km^2)	**HPAC** [Mean Area]	**VLSTRACK**
	64/674 [12/113]	22/111

152mm ARTILLERY GB (SARIN) (FIXED WIND = 8 Kph) SIMILAR SETTINGS: DOSAGE (1.8 m / 8 hr)

The accompanying chart provides a comparison of the predicted dosages for the similar settings case (e.g., the effects assumptions were identical).

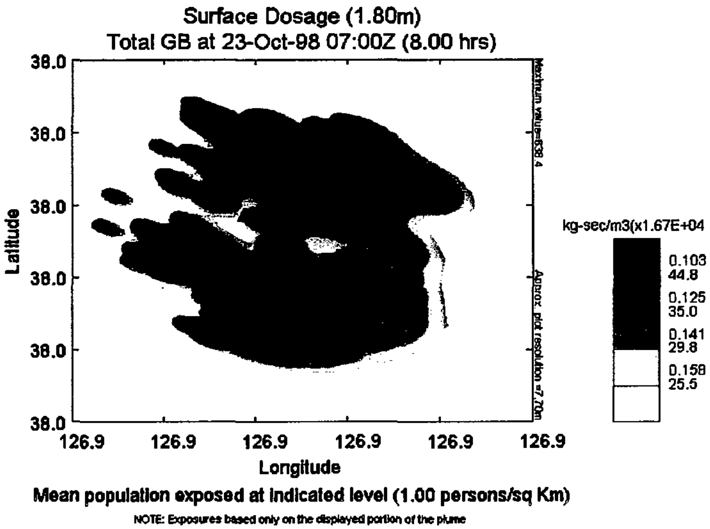
Both models predict dosage areas at LCt5 of less than 0.3 Km^2.

152mm Artillery GB (Sarin) (Fixed Wind = 8 Kph)
Similar Settings: Dosage (1.8 m / 8 hr)

Different scales shown

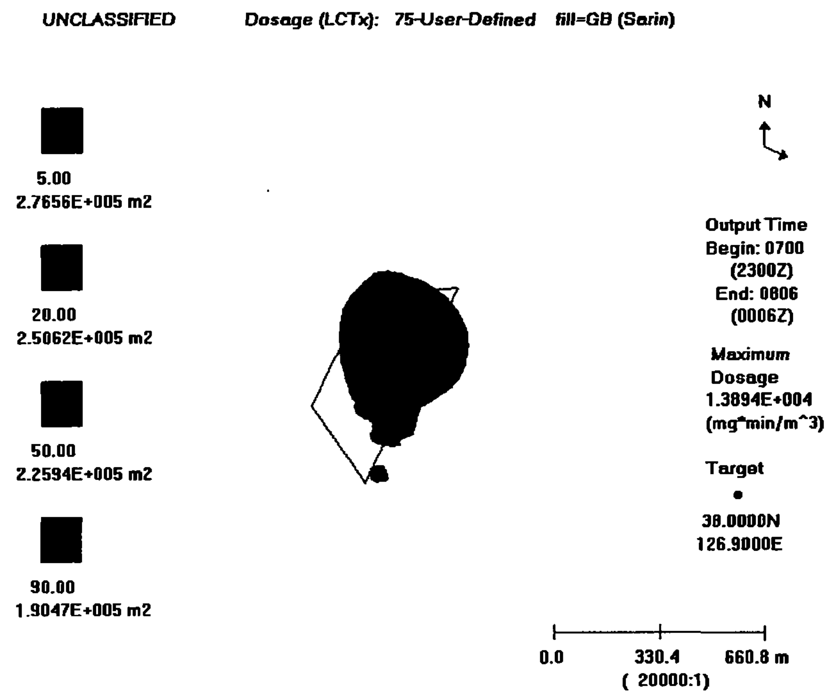
HPAC

8 hr



VLSTRACK

1 hr



"LCt5" L*W =
0.59 *0.51

At "LCt5" Estimated Area (Km^2)	HPAC [Mean Area]	VLSTRACK
	0.24 [0.16]	0.28

COMPARATIVE OBSERVATIONS FROM VX / THICKENED VX RELEASED FROM A BALLISTIC MISSILE

The final set of comparative chemical weapons trials that we examined considered 500 Kg of VX or thickened VX (TVX) delivered via a ballistic missile. Three burst altitudes were investigated – 300 m, 1,000 m, and 10,000 m.

For this set of scenarios, both models predicted hazards from inhalation to be small (always ≤ 0.54 Km^2). However, both models predicted surface deposition that, depending on the assumed lethal dosage via skin contact, could represent a hazard. We compared surface depositions predicted by the two models at the four HPAC-assumed lethal dosage via skin contact levels (LD2 = 1.4, LD20 = 4.5, LD50 = 10, and LD90 = 34 mg/m^2).

For the default settings comparisons, the predicted areas of hazard – lethality via skin contact – were significantly different. For example, the reported VLSTRACK "LD2" area size was between 3.8 and 7.5 times the size of the HPAC LD2 predicted AMDs for the trials done at 300 m and 1,000 m.

Adjusting the input settings so that they were as similar as possible led to predictions of surface deposition that were much more consistent between models. For the similar settings trials in which VX was released at 300 m or 1,000 m and TVX was released at 1,000 m, the differences in predictions were reduced to within a factor of 1.5 (10 percent difference for the 300 m VX trial, 53 percent difference for the 1,000m VX trial, and 10 percent difference for the TVX at 1,000 m trial). For the TVX release at 10,000 m, significant differences between HPAC and VLSTRACK predicted area sizes at "LD2" remained. These differences for the 10,000-m release may be due to different assumptions about the source term ("intercept" vs. nominal release) and/or different estimations of the height of the boundary layer or different assumptions about how material is transported through this layer.

Our analysis suggests that the factor that most influenced the differences in predicted surface deposition was the assumed mass median droplet diameter (MMD) – VLSTRACK assumed default values of 100 μm and 500 μm for VX and TVX (from a "medium range missile") while HPAC used 500 μm and 2,500 μm (from a "ballistic missile"), respectively. The HPAC calculations that were done with the smaller MMDs led to the larger surface deposition areas. This is consistent with the notion that the smaller droplets have larger surface-area-to-weight ratios, and thus remain airborne longer, than the larger droplets.

Predicted concentrations at the 0.01 $\mu g/m^3$ level differed significantly for all of the VX/TVX comparisons. In general, HPAC presented an area size that was much larger than the reported VLSTRACK value. This result was observed for both the default and similar settings cases.

Comparative Observations From VX / Thickened VX Released From a Ballistic Missile

- **For this scenario, both models predicted hazards from inhalation to be small or nonexistent**
- **Differences in model predictions of surface deposition were greatly reduced by standardizing the inputs**
  - In particular, using the same assumed mass median droplet diameter reduced the great variation between model predictions
  - However, smaller, yet potentially significant differences in hazard predictions remained
- **Predictions of lower-level concentrations differed dramatically**
  - HPAC produced larger areas

500 Kg OF VX FROM A MISSILE AT 300 m (FIXED WIND): DEFAULT SETTINGS, SURFACE DEPOSITION (≈ 2 hr)

The accompanying chart provides a comparison of the surface deposition predicted by HPAC 3.1 and VLSTRACK 1.6.3. This scenario considered VX (a persistent nerve agent) released via a ballistic missile at an altitude of 300 meters. This release is postulated to occur at 1200 local time in northwestern Virginia, over grassland, and under partly cloudy skies with a 13 Kph wind blowing from the south-southwest (203 degrees).

For the next nine slides, default settings were used where appropriate for both HPAC and VLSTRACK. With respect to surface deposition, contour levels were plotted at 1.4, 4.5, 10, and 34 mg/m^2. Assuming an exposed skin area of 1 m^2 with collocated human and agent, these values of surface deposition correspond to HPAC LD2, LD20, LD50, and LD90, respectively.

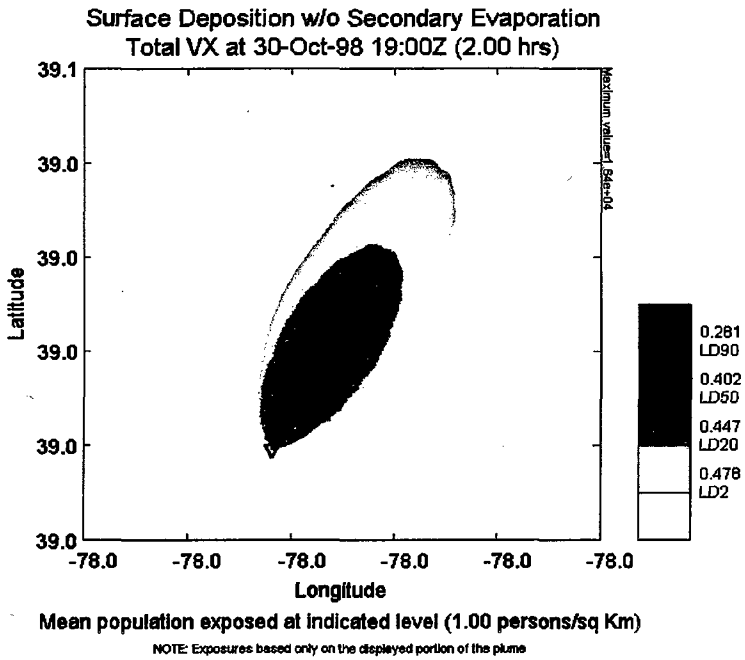
For this default settings case, the reported VLSTRACK area size at 1.4 mg/m^2 ("LD2") is 5.5 times the size of the estimated HPAC AMD and 25 times the size of the HPAC mean area.

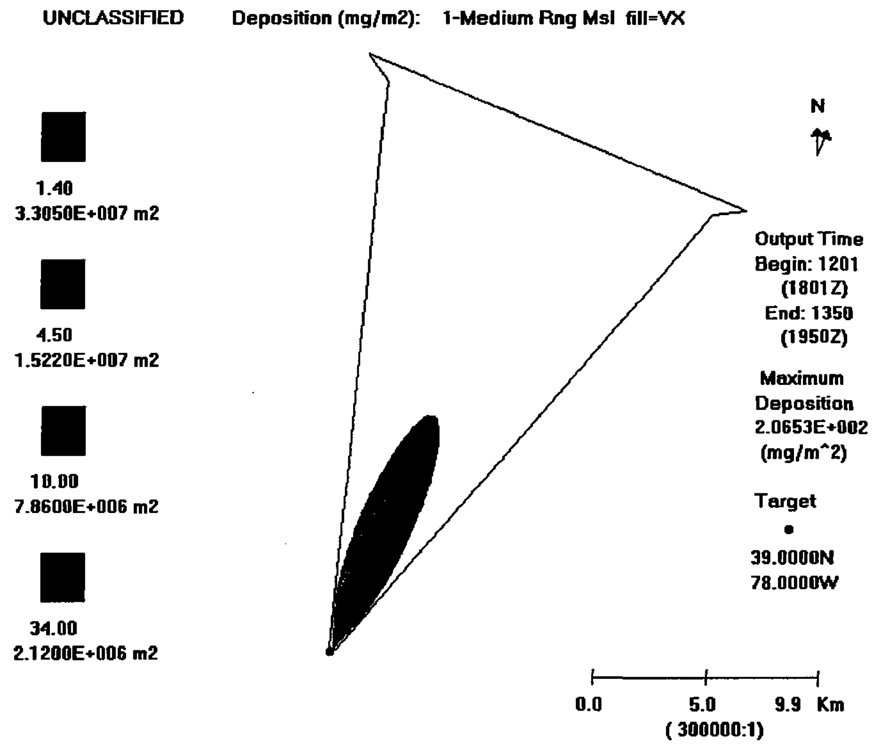
500 Kg of VX from a Missile at 300 m (Fixed Wind): Default Settings, Surface Deposition (≈ 2 hr)

HPAC

VLSTRACK

Different scales shown





L*W =
4.6 * 1.6

At 1.4 mg/m² Estimated Area (Km²)	HPAC [Mean Area]	VLSTRACK
	6 [1.3]	33

500 Kg OF VX FROM A MISSILE AT 1,000 m (FIXED WIND): DEFAULT SETTINGS, SURFACE DEPOSITION (≈ 3.5 hr)

The chart opposite is similar to the last chart. This time a ballistic missile release of VX at an altitude of 1,000 meters is examined.

For this default settings case, the reported VLSTRACK area size at 1.4 mg/m^2 ("LD2") is 3.8 times the size of the estimated HPAC AMD and 12 times the size of the HPAC mean area.

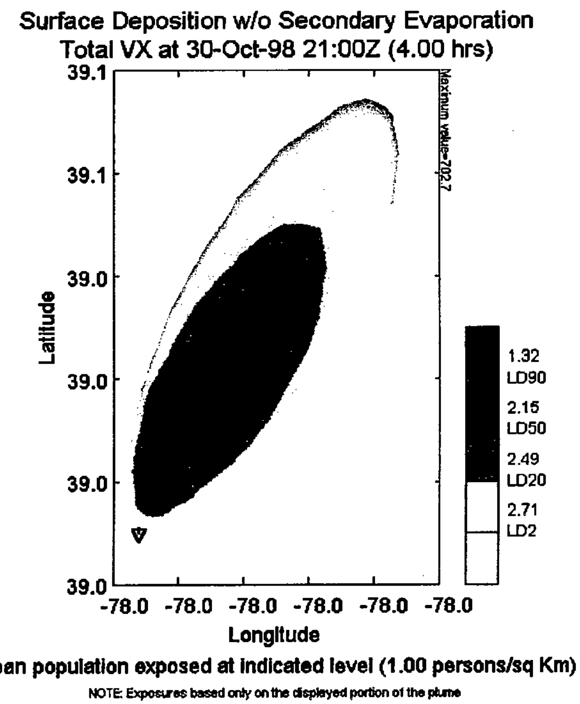
500 Kg of VX from a Missile at 1,000 m (Fixed Wind): Default Settings, Surface Deposition (≈ 3.5 hr)

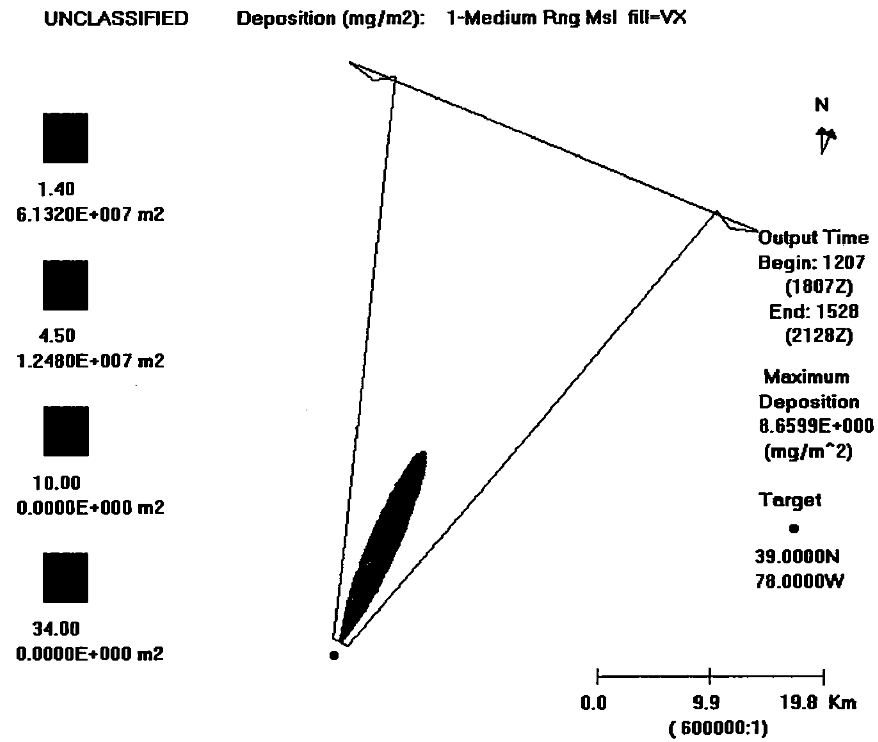
HPAC

VLSTRACK

Different scales shown

L*W =
8.2 * 2.5





At 1.4 mg/m^2 Estimated Area (Km^2)	**HPAC** [Mean Area]	**VLSTRACK**
	16 [5]	61

500 Kg OF THICKENED VX FROM A MISSILE AT 1,000 m (FIXED WIND): DEFAULT SETTINGS, SURFACE DEPOSITION (40 min)

The chart opposite compares the predictions of surface deposition for the release of thickened VX from a ballistic missile at an altitude of 1,000 meters.[43]

For this default settings case, the reported VLSTRACK area size at 1.4 mg/m^2 ("LD2") is 7.5 times the size of the estimated HPAC AMD and more than 120 times the size of the HPAC mean area.

[43] It is expected that some chemical warfare agents, for example, VX, may be modified by the addition of polymers or other materials, thickening them to higher viscosities. In part, this thickening process is meant to increase the agent's persistence by reducing evaporation.

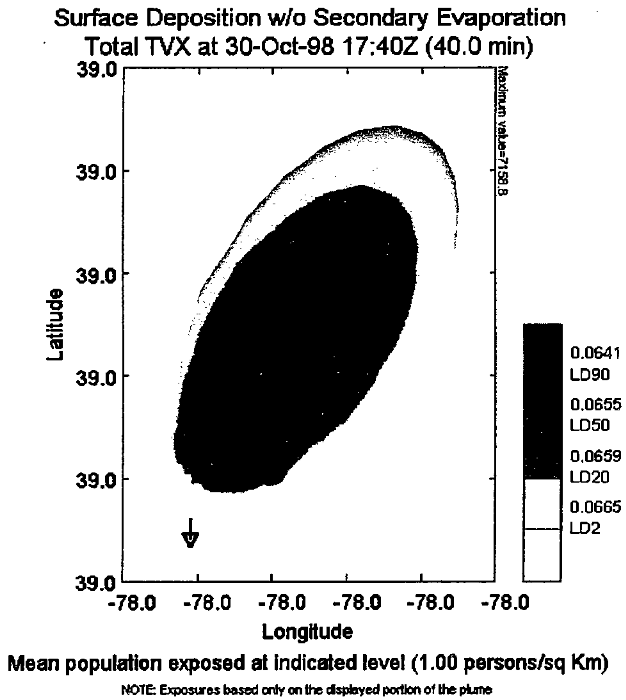
500 Kg of Thickened VX from a Missile at 1,000 m (Fixed Wind): Default Settings, Surface Deposition (40 min)

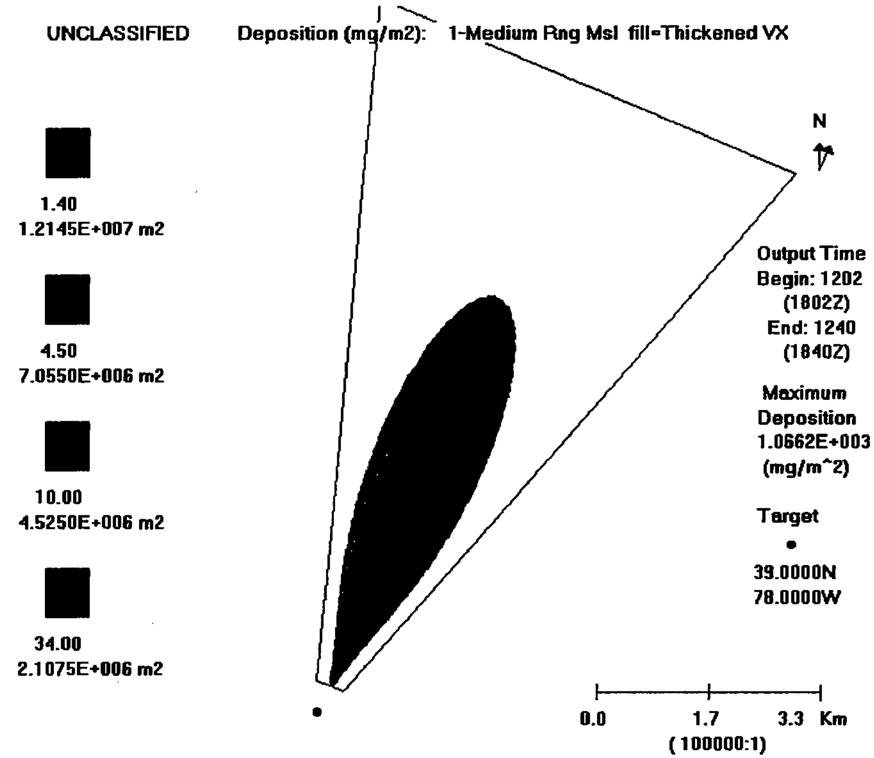
HPAC

VLSTRACK

Different scales shown

L*W =
2.12 * 0.96





At 1.4 mg/m² Estimated Area (Km²)	HPAC [Mean Area]	VLSTRACK
	1.6 [0.098]	12

500 Kg OF THICKENED VX FROM A MISSILE AT 10,000 m (FIXED WIND): DEFAULT SETTINGS, SURFACE DEPOSITION (≈ 2.7 hr)

The accompanying chart compares surface deposition predictions from the two models for the release of thickened VX from a ballistic missile at an altitude of 10,000 meters.

For this default settings case, the reported VLSTRACK area size at 1.4 mg/m^2 ("LD2") is 13 percent smaller than the estimated HPAC AMD and 4.1 times the size of the HPAC mean area.

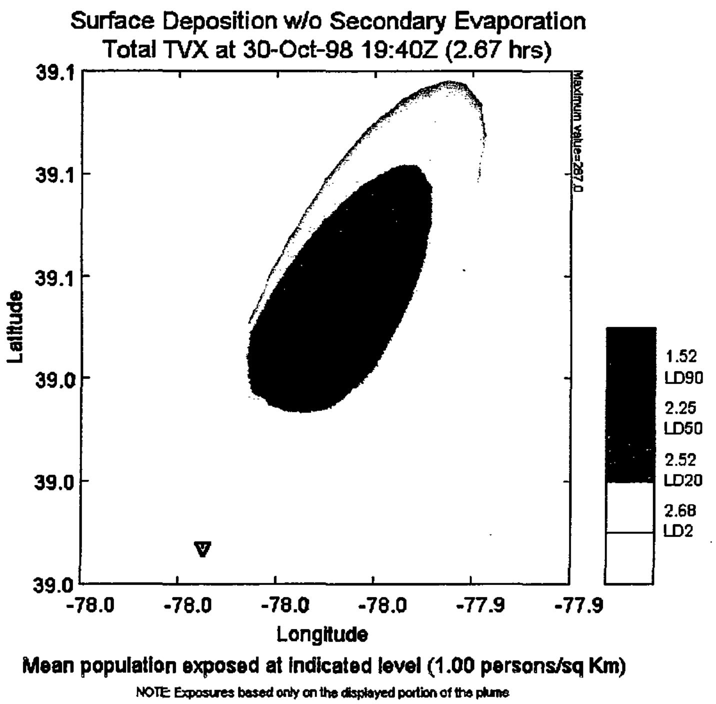
500 Kg of Thickened VX from a Missile at 10,000 m (Fixed Wind): Default Settings, Surface Deposition (≈ 2.7 hr)

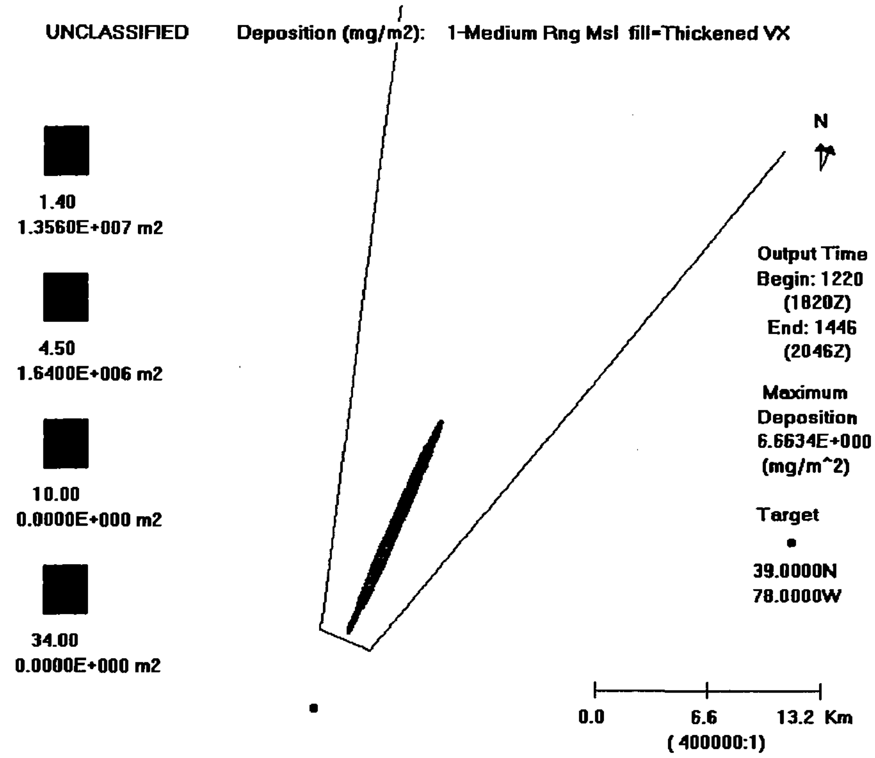
HPAC

VLSTRACK

Different scales shown

L*W = 7.7 * 2.6





At 1.4 mg/m^2 Estimated Area (Km^2)	HPAC [Mean Area]	VLSTRACK
	16 [3.4]	14

500 Kg OF VX FROM A MISSILE AT 300 m DEFAULT SETTINGS (FIXED WIND): DOSAGE AND CONCENTRATION (1.8 m)

The HPAC 1-hour concentration and 8-hour dosage predictions are shown at right. VLSTRACK did not predict a concentration at 0.01μg/m^3 – the lowest level available for plotting in VLSTRACK.

The default HPAC dosage plot presents contours at a threshold level (miosis), at incapacitation levels (ICt5 and ICt50), and at lethal dosages (LCt50 and LCt90). The HPAC ICt50 value is based on a dosage of 11 mg-min/m^3. VLSTRACK did not predict a dosage above 8.2 mg-min/m^3.

The gray area, shown on the upper HPAC plot, corresponds to the more highly populated area for this portion of Northern Virginia (Berryville, VA).

500 Kg of VX from a Missile at 300 m Default Settings (Fixed Wind): Dosage and Concentration (1.8 m)

	HPAC	VLSTRACK
Different scales shown		

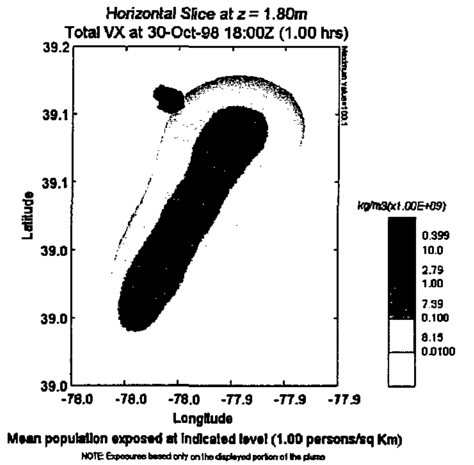
HPAC

VLSTRACK

Different scales shown

Concentration
1 hour

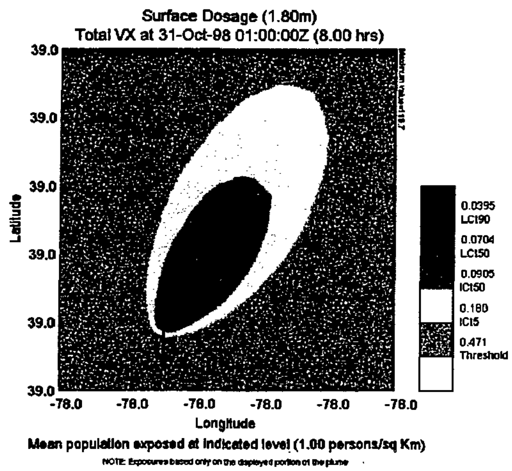
L*W =
20.3 * 6.2



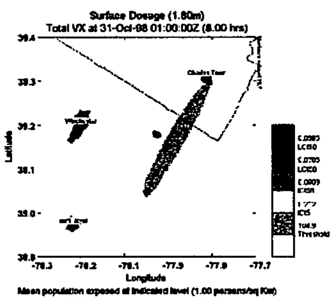
No concentration above 0.01 mg/m³ observed

Dosage
8 hours

L*W =
0.85 * 0.35



No dosage above VLSTRACK LCt5 (8.2 mg-min/m³) observed



At 0.01mg/m³ (1 hr) / ICt5 (8 hours & 11 mg-min/m³)

	HPAC [Mean Area]
Estimated Area (Km²)	99/0.23 [8/0.21]

500 Kg OF VX FROM A MISSILE AT 1,000 m DEFAULT SETTINGS (FIXED WIND): DOSAGE AND CONCENTRATION (1.8 m)

The HPAC predicted 1-hour concentration for the 1,000-meter missile burst with 500 Kg of VX is shown at right. VLSTRACK did not predict a concentration at 0.01 $\mu g/m^3$.

The default HPAC dosage plot reported a miosis hazard (0.04 mg-min/min^3). Neither model predicted hazards at higher dosage levels.

500 Kg of VX from a Missile at 1,000 m Default Settings (Fixed Wind): Dosage and Concentration (1.8 m)

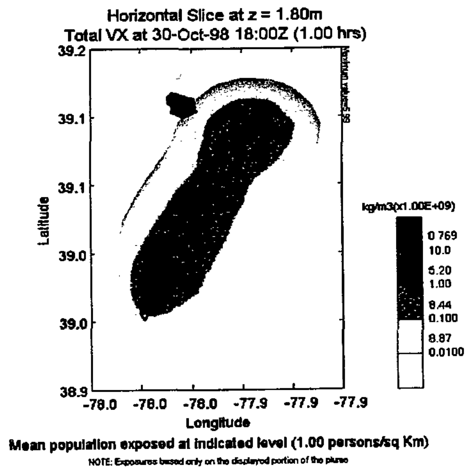
HPAC

VLSTRACK

Different scales shown

Concentration
1 hour

L*W =
20.2 * 7.8



No concentration above 0.01 mg/m³ observed

Dosage
8 hours

No dosage above HPAC ICt5 (11 mg-min/m³) observed

HPAC does show miosis (0.04 mg-min/m³) hazard

No dosage above VLSTRACK LCt5 (8.2 mg-min/m³) observed

At 0.01mg/m³ (1 hr)
Estimated Area (Km²)

HPAC **[Mean Area]**
124 [9]

500 Kg OF THICKENED VX FROM A MISSILE AT 1,000 m DEFAULT SETTINGS (FIXED WIND): DOSAGE AND CONCENTRATION (1.8 m)

The predictions for concentration and dosage for the release of thickened VX at 1,000 meters are shown at right. Only HPAC predicted a 1-hour concentration level above 0.01 $\mu g/m^3$.

HPAC predicted a small area – less than 0.03 Km^2 – in which the ICt5 (11 mg-min/m^3) level was reached. VLSTRACK showed a small (0.04 Km^2) area at the 8.2 mg-min/m^3 dosage level that started to appear at 12 hours in the region of the heaviest predicted surface deposition. The build-up of dosage shown in the VLSTRACK prediction appears to be due to secondary evaporation.

500 Kg of Thickened VX from a Missile at 1,000 m Default Settings (Fixed Wind): Dosage and Concentration (1.8 m)

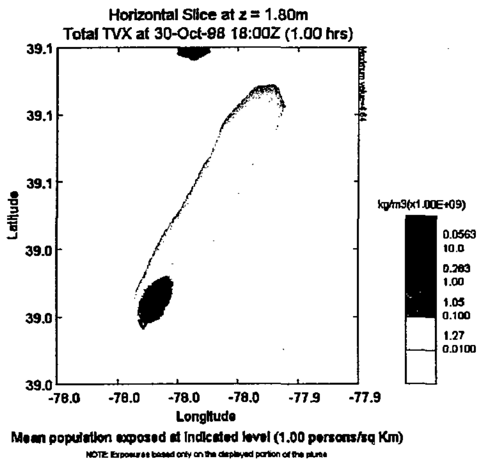
HPAC

VLSTRACK

Different scales shown

Concentration
1 hour

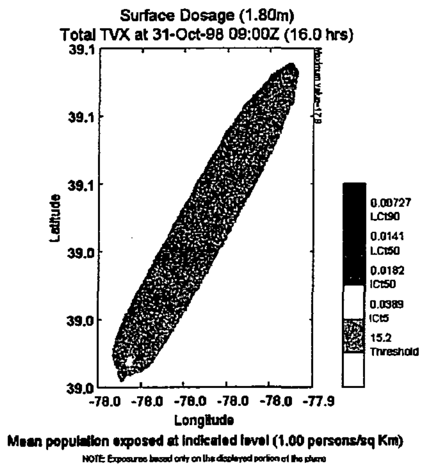
L*W =
15.2 * 2.2

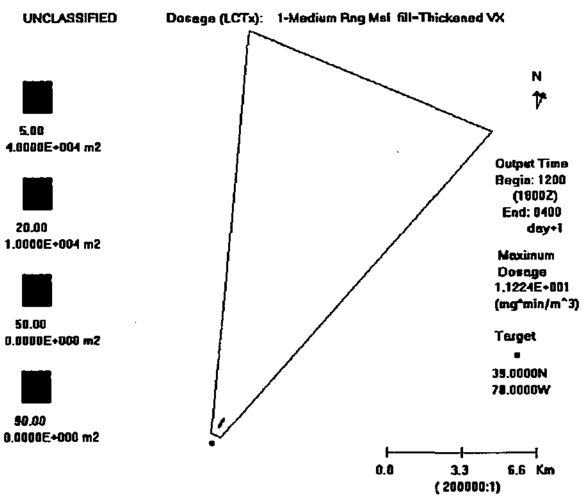


No concentration above
0.01 mg/m³ observed

Dosage
16 hours

L*W =
0.24 * 0.12





At 0.01mg/m³ (1 hr) / Dosage at 16 hr ICt5 (11 mg-min/m³) or LCt5 (8.2 mg-min/m³)

	HPAC [Mean Area]	VLSTRACK
Estimated Area (Km²)	26/0.03 [1.3/0.007]	na/0.04

500 Kg OF THICKENED VX FROM A MISSILE AT 10,000 m DEFAULT SETTINGS (FIXED WIND): CONCENTRATION (1.8 m)

For the case involving thickened VX released at 10,000 meters, the 4- and 12-hour concentrations are shown for both models on the accompanying slide. Depending upon the HPAC estimate of area size compared (AMD or mean area), the VLSTRACK reported area is 5.1 or 6.7 times smaller at 4 hours and 8.8 or 12.7 times smaller at 12 hours.

The gray areas, shown on the lower HPAC plot, correspond to the more highly populated areas for this portion of Northern Virginia (Berryville, VA) and Maryland (Charles Town, MD).

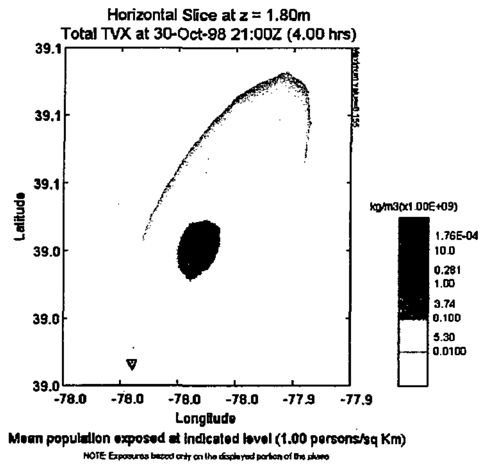
500 Kg of Thickened VX from a Missile at 10,000 m
Default Settings (Fixed Wind): Concentration (1.8 m)

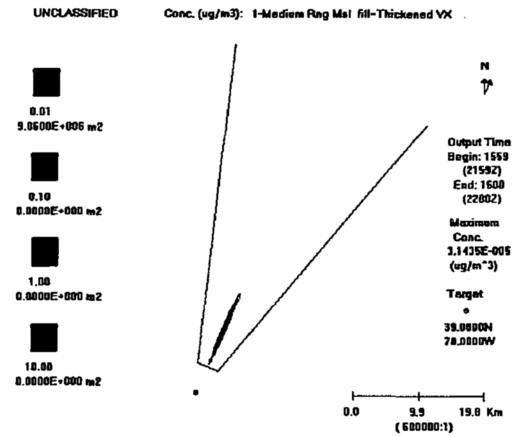
HPAC | VLSTRACK

Different scales shown

Concentration
4 hour

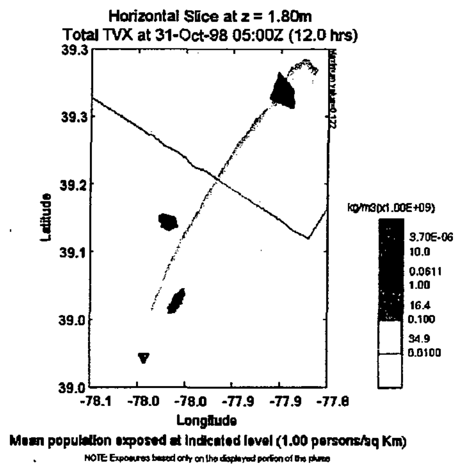
L*W =
12.2 * 4.8

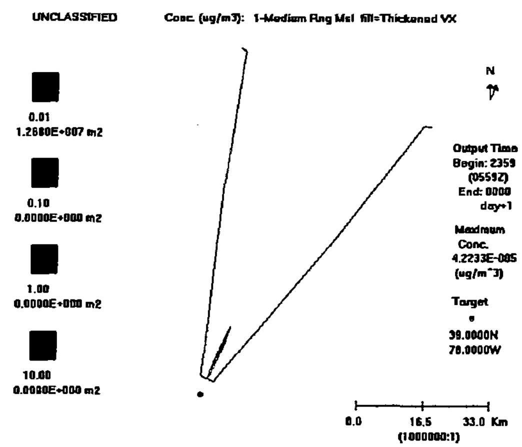




12 hours

L*W =
37.5 * 5.6





At 0.01mg/m³ (4 hr/12 hr) Estimated Area (Km²)	**HPAC** [Mean Area]	**VLSTRACK**
	46/165 [60/115]	9/13

500 Kg OF THICKENED VX FROM A MISSILE AT 10,000 m DEFAULT SETTINGS (FIXED WIND): DOSAGE (1.8 m)

With respect to predicted dosage for the thickened VX release at 10,000 meters, neither model shows serious hazards. HPAC does predict an area of miosis.

500 Kg of Thickened VX from a Missile at 10,000 m Default Settings (Fixed Wind): Dosage (1.8 m)

Different scales shown

HPAC

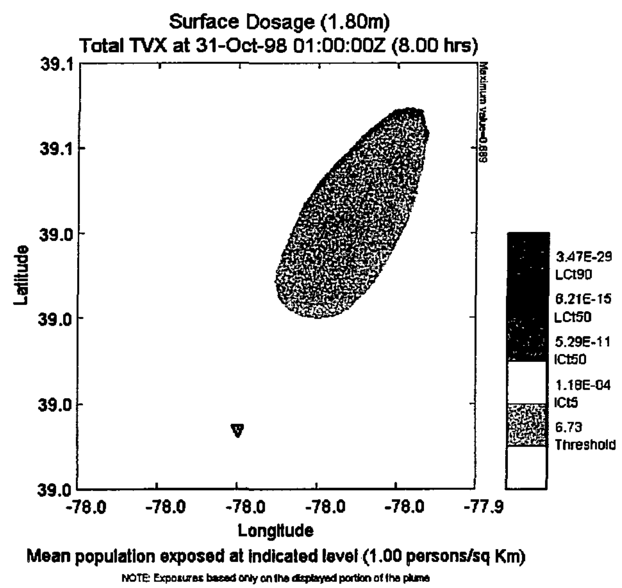
No dosage above HPAC ICt5 (11 mg-min/m^3) observed

HPAC does show miosis (0.04 mg-min/m^3) hazard

VLSTRACK

No dosage above VLSTRACK LCt5 (8.2 mg-min/m^3) observed

Dosage
8 hours



DEFAULT VS. "SIMILAR" SETTINGS FOR VX/THICKENED VX FROM BALLISTIC MISSILE TRIALS

The table shown on the accompanying chart lists the changes that were made in order to create as similar a set of initial conditions as possible for the VX/thickened VX ballistic missile release that we examined. The line source length, fall angle, dissemination efficiency, and mass median droplet diameter were all adjusted in HPAC to conform to the default VLSTRACK values. Both models assumed a droplet distribution sigma of 1.7 μm for VX and TVX. The assumed wind measurement height was changed from 2 to 10 m in VLSTRACK to be consistent with the value assumed by HPAC.

In doing this trial, we noted that for this location (Virginia), VLSTRACK and HPAC assumed a different definition of "local time." For the default VX trials described to this point, the release start time was set at 1200 local time for each model. However, VLSTRACK converted this value to 18:00 Zulu and HPAC converted this time to 17:00 Universal Time Coordinates (UTC also known as Greenwich Mean Time – GMT – or Zulu). It appears that VLSTRACK defines local time as Standard Time throughout the year and makes no adjustments for daylight saving time. On the other hand, HPAC defaults to a local-zulu time conversion that is consistent with daylight saving time throughout the year for this particular region. This time conversion factor can be easily adjusted in HPAC.

For the similar settings comparisons that follow, the dosage levels – lethal concentration levels – were set equal to the assumed VLSTRACK values.

Default vs. "Similar" Settings for VX/Thickened VX from Ballistic Missile Trials

Model Parameter	*Default (VX/Thickened VX)*		*"Similar" (VX/Thickened VX)*	
	VLSTRACK	HPAC	VLSTRACK	HPAC
Line Source Length (m)	200	300	200	200
Fall Angle (deg)	45	70	45	45
Dissemination Efficiency (%)	60	100	60	60
Mass Median Drop Diameter (μm)	100/500	500/2,500	100/500	100/500
Start Time (UTC)	18:00	17:00	17:00	17:00
Wind Measurement Height (m)	2	10	10	10

Effects assumptions were set equal to the reported VLSTRACK values (mg-min/m^3):

$$\boxed{\begin{aligned} LCt5 &= 8.2225 \\ LCt20 &= 11.028 \\ LCt50 &= 15.000 \\ LCt90 &= 23.961 \end{aligned}}$$

500 Kg OF VX FROM A MISSILE AT 300 m (FIXED WIND): SIMILAR SETTINGS, SURFACE DEPOSITION (≈ 2.5 hr)

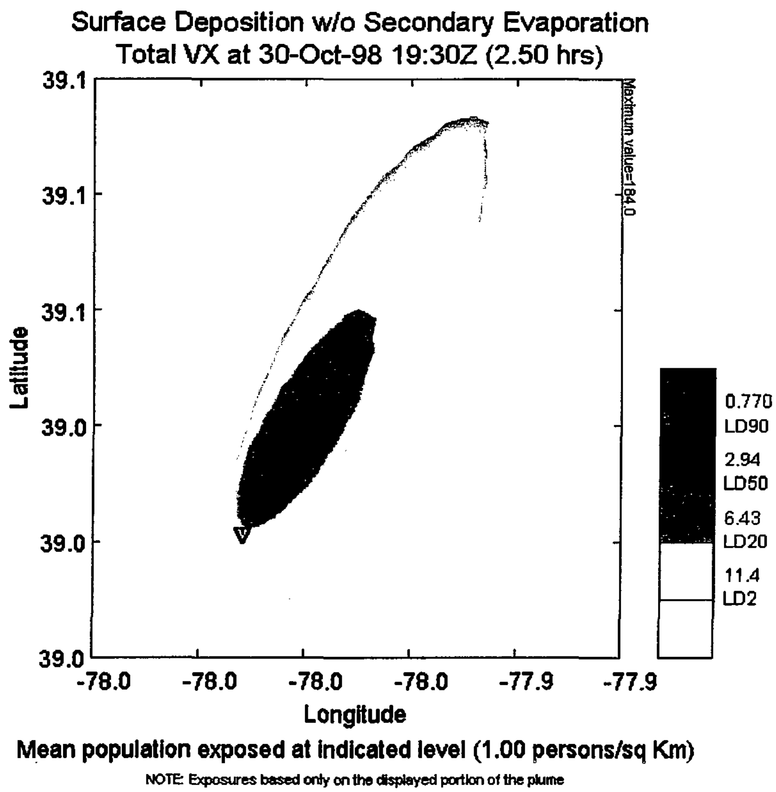
The chart opposite compares the surface deposition contours predicted by HPAC and VLSTRACK when similar settings are used for the "VX released at 300 meters" case. The estimated LD2 areas are quite similar – within 10 percent – for VLSTRACK and HPAC. The default settings calculations led to significantly different surface deposition predictions by the two models.

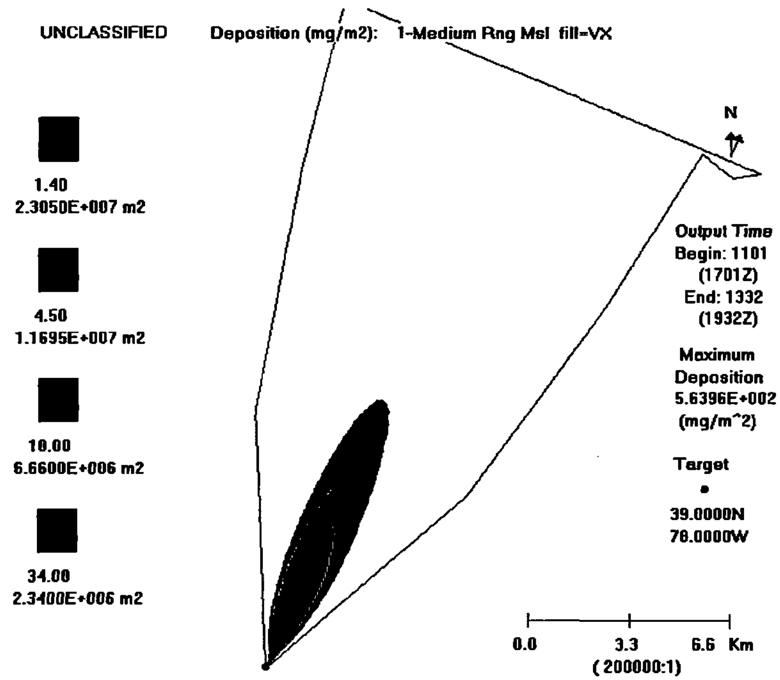
500 Kg of VX from a Missile at 300 m (Fixed Wind): Similar Settings, Surface Deposition (≈ 2.5 hr)

HPAC

VLSTRACK

Different scales shown





L*W = 11.9 * 2.7

At 1.4 mg/m² Estimated Area (Km²)	HPAC [Mean Area]	VLSTRACK
	25 [22]	23

500 Kg OF VX FROM A MISSILE AT 1,000 m (FIXED WIND): SIMILAR SETTINGS, SURFACE DEPOSITION (≈ 4 hr)

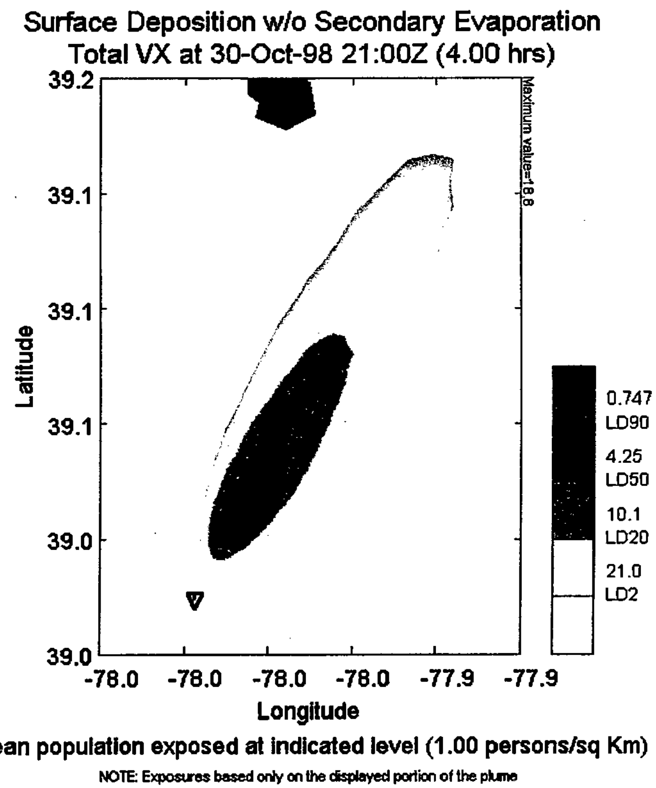
For the trial in which VX was released from a ballistic missile at 1,000 meters, VLSTRACK predicts an LD2 area that is 53 percent larger than the HPAC AMD and 77 percent larger than the HPAC mean area. For the default settings case, the VLSTRACK prediction was 3.8 and 12 times larger than the HPAC values for AMD and mean area, respectively. The adoption of similar settings appears to have significantly reduced the variance in predictions between HPAC and VLSTRACK for this particular scenario.

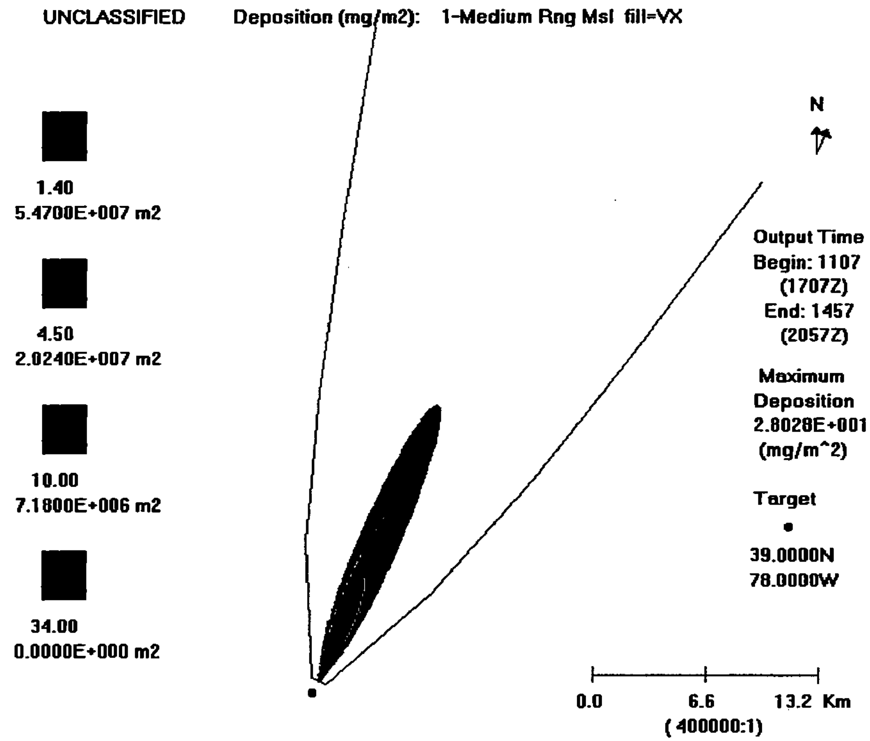
500 Kg of VX from a Missile at 1,000 m (Fixed Wind): Similar Settings, Surface Deposition (≈ 4 hr)

HPAC | VLSTRACK

Different scales shown

L*W =
14.6 * 3.1





At 1.4 mg/m² Estimated Area (Km²)	HPAC [Mean Area]	VLSTRACK
	36 [31]	55

500 Kg OF THICKENED VX FROM A MISSILE AT 1,000 m (FIXED WIND): SIMILAR SETTINGS, SURFACE DEPOSITION (50 min)

Again, the chart opposite, corresponding to the similar settings trial, shows much less variance than the default settings trial. In this case, the HPAC AMD value is 2.7 times larger than the reported VLSTRACK area. The VLSTRACK value is 10 percent larger than the reported HPAC mean area.

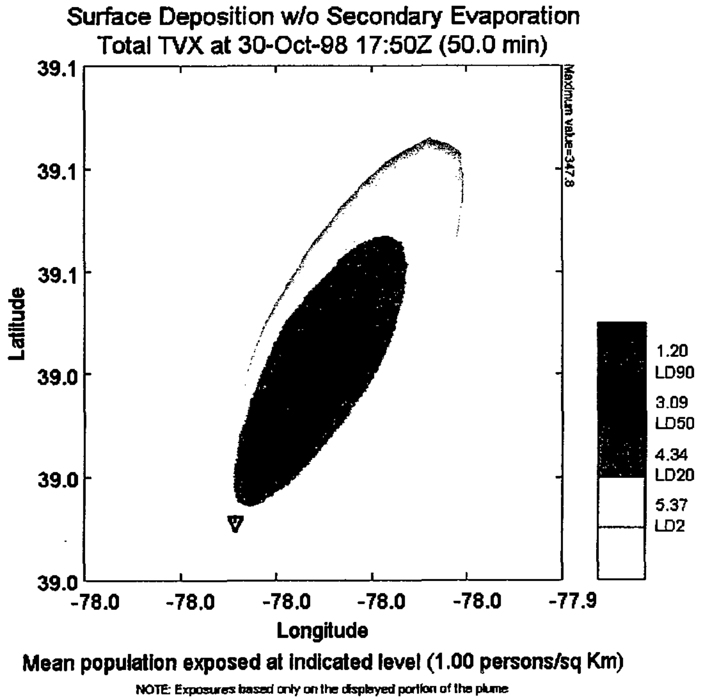
500 Kg of Thickened VX from a Missile at 1,000 m (Fixed Wind): Similar Settings, Surface Deposition (50 min)

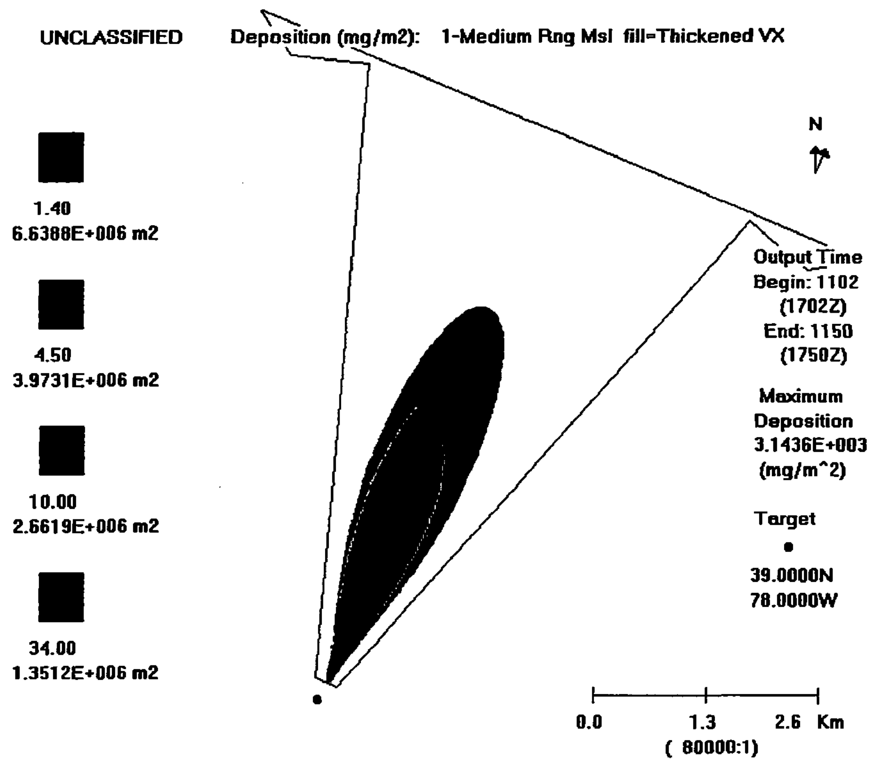
HPAC

VLSTRACK

Different scales shown

L*W =
8.8 * 2.6





At 1.4 mg/m^2 Estimated Area (Km^2)	HPAC [Mean Area]	VLSTRACK
	18 [6.0]	6.6

500 Kg OF THICKENED VX FROM A MISSILE AT 10,000 m (FIXED WIND): SIMILAR SETTINGS, SURFACE DEPOSITION (≈ 3.5 hr)

The accompanying chart provides a comparison of the surface deposition predicted by HPAC and VLSTRACK in the case in which thickened VX is released at 10,000 meters.

HPAC predicts area sizes that are 5.3 (AMD) or 4.4 (mean area) times larger than the reported VLSTRACK value. For this case, the predictions with the default input settings actually led to predictions that were more alike than the predictions using the similar settings!

First, we have confirmed that for a release specified at this altitude, VLSTRACK greatly changes the assumed initial vapor/liquid fraction. For example, for the 1,000 m release of thickened VX, VLSTRACK assumes that almost all (>99 percent) of the initial mass is in liquid form. For the 10,000 m thickened VX release, VLSTRACK assumes that vapor represents about 85 percent of the. **This change, relative to the lower altitude releases, reflects VLSTRACK's assumption that ballistic missile releases at these higher altitudes are due to intercepts by defensive systems.** There was no evidence of this sort of a change in source term assumption for HPAC.

It can also be seen that HPAC predicted, for this particular case, two areas of surface deposition at the LD2 level. VLSTRACK shows only one area which appears to roughly correspond to the lower HPAC area (not the one that covers Charles Town, MD). This difference may be a reflection of the lack of vapor deposition in VLSTRACK, as discussed earlier, or it may be due to other factors. Other factors could include differences in the computation of the boundary layer and differences in the modeling of cloud transport through the layer.

500 Kg of Thickened VX from a Missile at 10,000 m (Fixed Wind): Similar Settings, Surface Deposition (≈ 3.5 hr)

HPAC

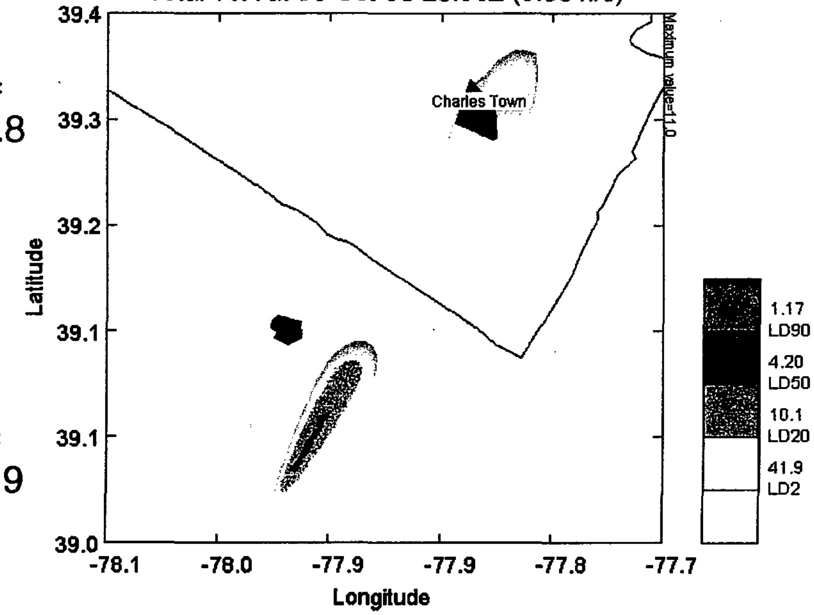
VLSTRACK

Different scales shown

Surface Deposition w/o Secondary Evaporation
Total TVX at 30-Oct-98 20:30Z (3.50 hrs)

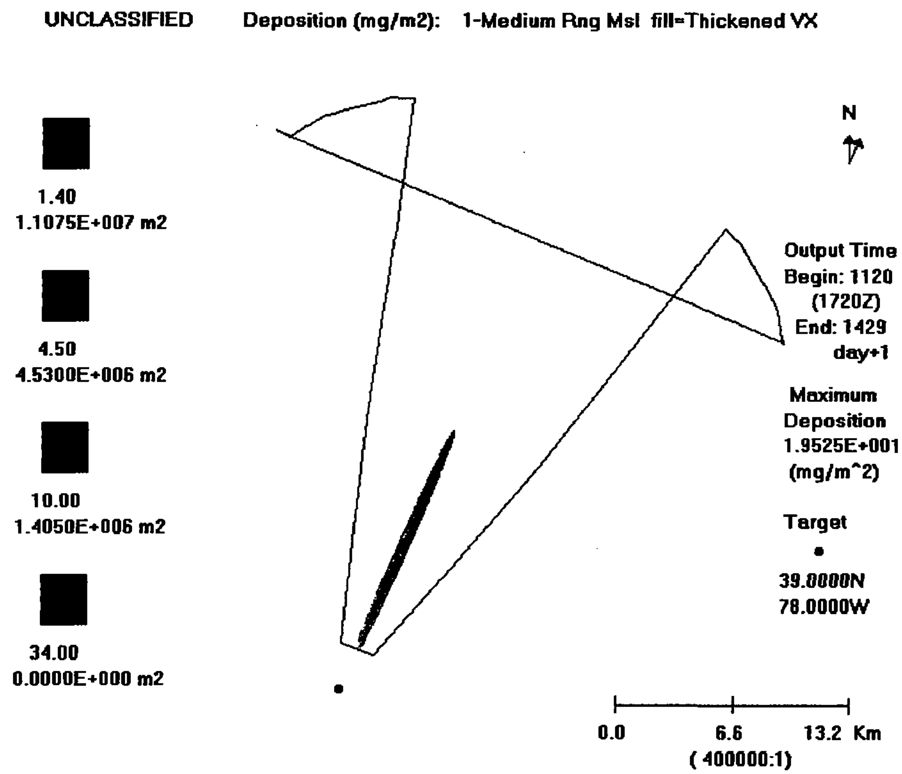
Upper
L*W =
10.2 * 3.8

Lower
L*W =
12.4 * 2.9



Mean population exposed at indicated level (1.00 persons/sq Km)

NOTE: Exposures based only on the displayed portion of the plume



At 1.4 mg/m² Estimated Area (Km²)	HPAC [Mean Area]	VLSTRACK
	59 [48]	11

500 Kg OF VX FROM A MISSILE AT 300 m SIMILAR SETTINGS (FIXED WIND): CONCENTRATION (1.8 m)

The predicted 1- and 4-hour concentration contours for the similar settings 300-meter release of VX are shown on the chart at right. The area associated with the HPAC predicted 0.01 $\mu g/m^3$ contour appears significantly larger than the reported VLSTRACK area. This same result was observed at this relatively low-level concentration for the GD sprayer and GB artillery scenarios.

500 Kg of VX from a Missile at 300 m Similar Settings (Fixed Wind): Concentration (1.8 m)

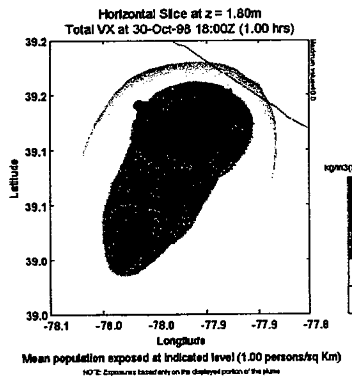
HPAC

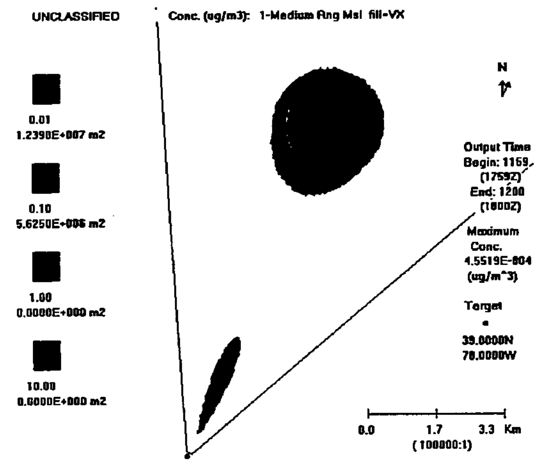
VLSTRACK

Different scales shown

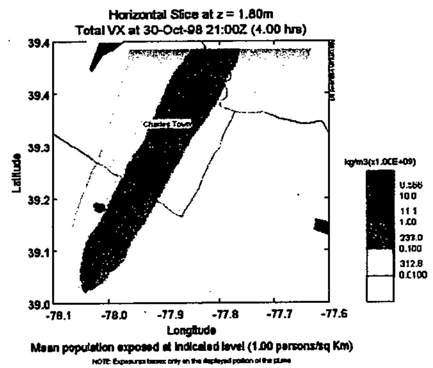
1 hour

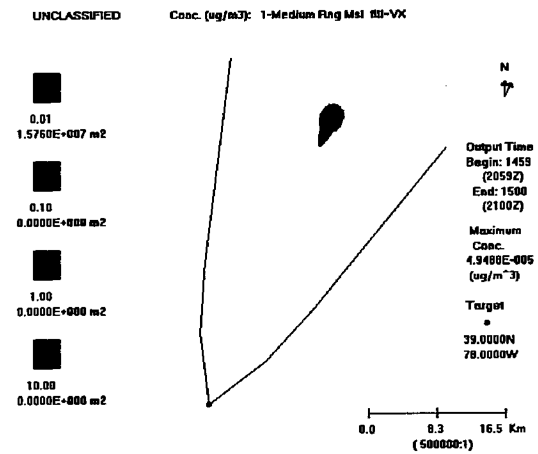
L*W =
23.8 * 15.3





4 hours





At 0.01 mg/m³ (1 hr/4 hr) Estimated Area (Km²)	**HPAC** [Mean Area]	**VLSTRACK**
	287/na [19/>314	12/16

500 Kg OF VX FROM A MISSILE AT 1,000 m SIMILAR SETTINGS (FIXED WIND): CONCENTRATION (1.8 m)

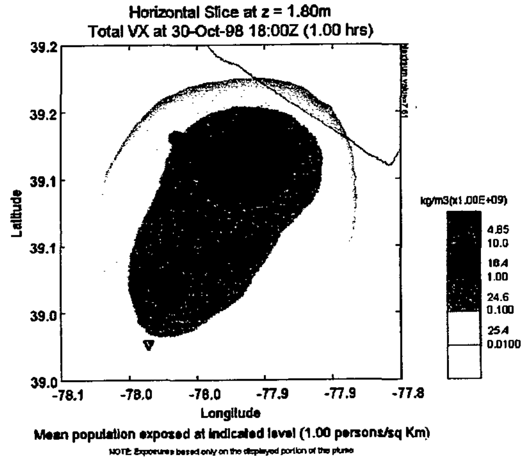
The predicted 1- and 4-hour concentration contours are shown on the chart at right for the case that considered VX released at 1,000 meters from a ballistic missile. The predicted HPAC areas at 0.01 $\mu g/m^3$ appear to be significantly larger than the reported VLSTRACK values with the exception of the 1-hour HPAC reported mean area value (26 Km^2).

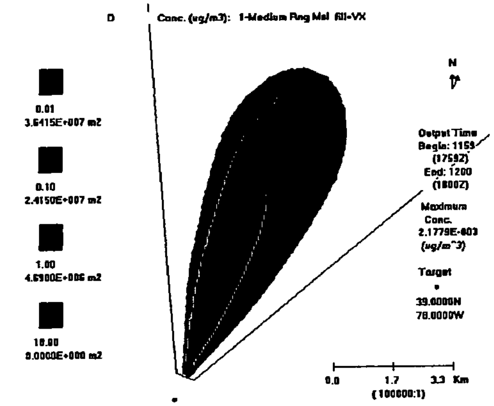
500 Kg of VX from a Missile at 1,000 m Similar Settings (Fixed Wind): Concentration (1.8 m)

	HPAC	VLSTRACK
Different scales shown		

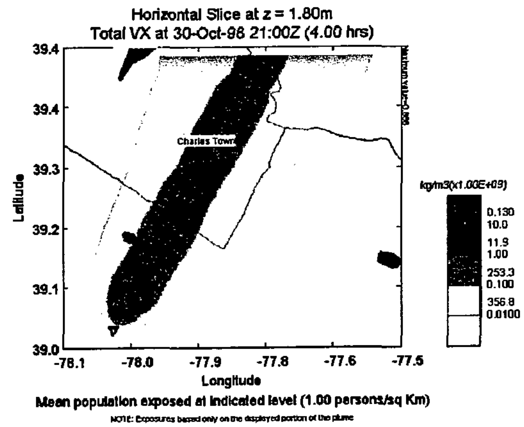
1 hour

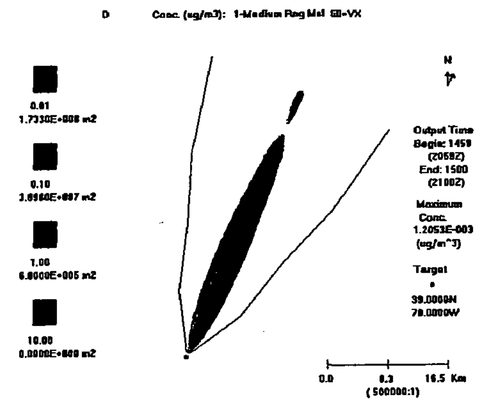
L*W = 23.4 * 16.2





4 hours





At 0.01 mg/m³ (1 hr/4 hr) Estimated Area (Km²)	**HPAC** [Mean Area]	**VLSTRACK**
	298/na [26/>357]	36/173

500 Kg OF THICKENED VX FROM A MISSILE AT 1,000 m SIMILAR SETTINGS (FIXED WIND): CONCENTRATION (1.8 m)

Predicted concentrations at 1 and 8 hours are compared for the case of thickened VX released at 1,000 meters on the accompanying chart. Again, HPAC predicts areas at the 0.01 μg/m^3 level that are much larger than those predicted by VLSTRACK.

500 Kg of Thickened VX from a Missile at 1,000 m Similar Settings (Fixed Wind): Concentration (1.8 m)

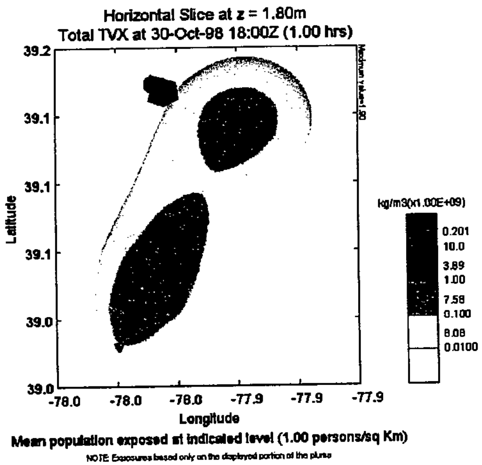
HPAC

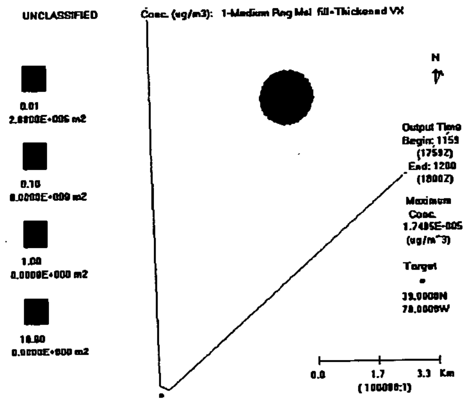
VLSTRACK

Different scales shown

1 hour

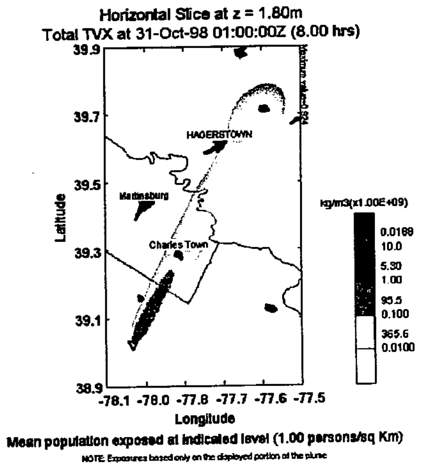
L*W = 20.0 * 6.7

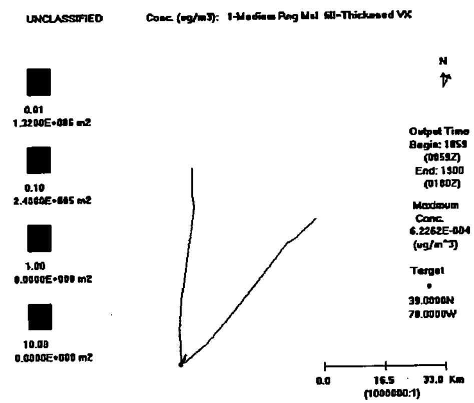




8 hours

L*W = 99.9 * 11.0





At 0.01mg/m³ (1 hr/8 hr) Estimated Area (Km²)	**HPAC** [Mean Area]	**VLSTRACK**
	106/861 [8.1/480]	2.9/1.3

500 Kg OF THICKENED VX FROM A MISSILE AT 10,000 m SIMILAR SETTINGS (FIXED WIND): CONCENTRATION (1.8 m)

Predicted concentrations at 1 and 7 hours are compared for the case of thickened VX released at 10,000 meters on the accompanying chart. **Low-level concentrations predicted by HPAC appear to be quite different from those predicted by VLSTRACK, even for the cases in which similar input settings were used**

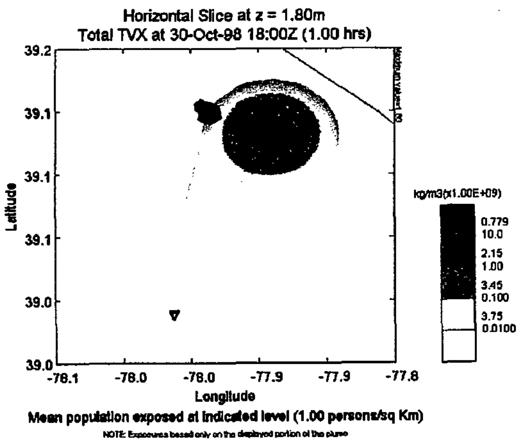
500 Kg of Thickened VX from a Missile at 10,000 m
Similar Settings (Fixed Wind): Concentration (1.8 m)

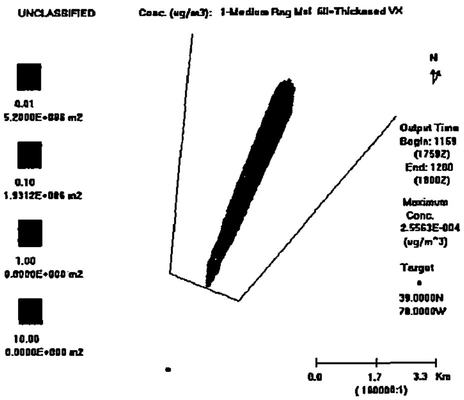
HPAC | VLSTRACK

Different scales shown

1 hour

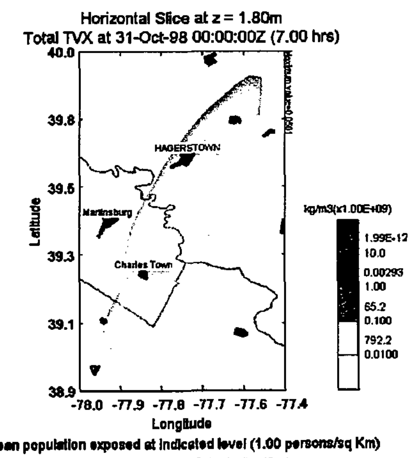
L*W =
14.7 * 7.2

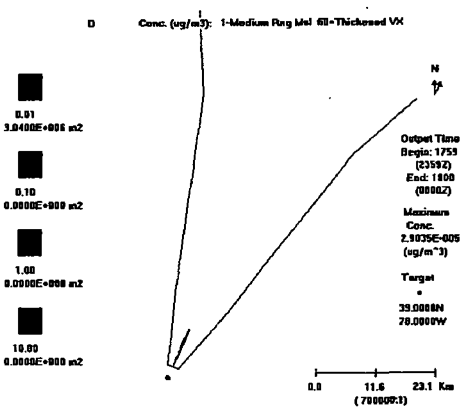




7 hours

L*W =
99.0 * 20.5





At 0.01mg/m³ (1 hr/7 hr) Estimated Area (Km²)	HPAC [Mean Area]	VLSTRACK
	83/1,592 [48/912]	5.2/0.30

500 Kg OF VX FROM A MISSILE AT 300 m SIMILAR SETTINGS (FIXED WIND): DOSAGE (1.8 m / 16 hr)

For the case of VX dispensed at 300 meters by a ballistic missile, both models predict small areas of LCt5. The reported VLSTRACK area is 2.2 and 1.5 times larger than the HPAC AMD and mean areas, respectively. The reported VLSTRACK dosage started to appear at 3 hours and was located 1.8 m above the heaviest predicted surface deposition. Therefore, we speculate that this dosage is associated with secondary evaporation

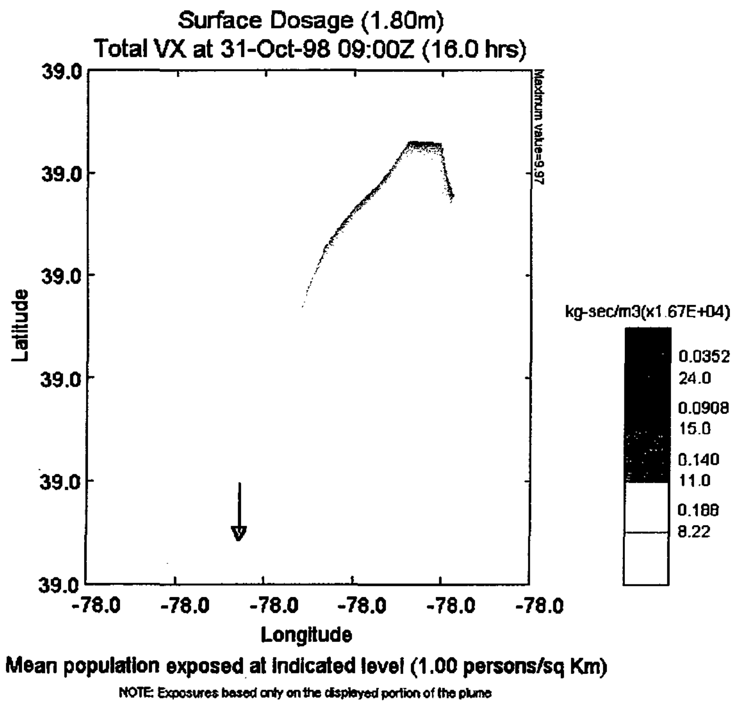
500 Kg of VX from a Missile at 300 m Similar Settings (Fixed Wind): Dosage (1.8 m / 16 hr)

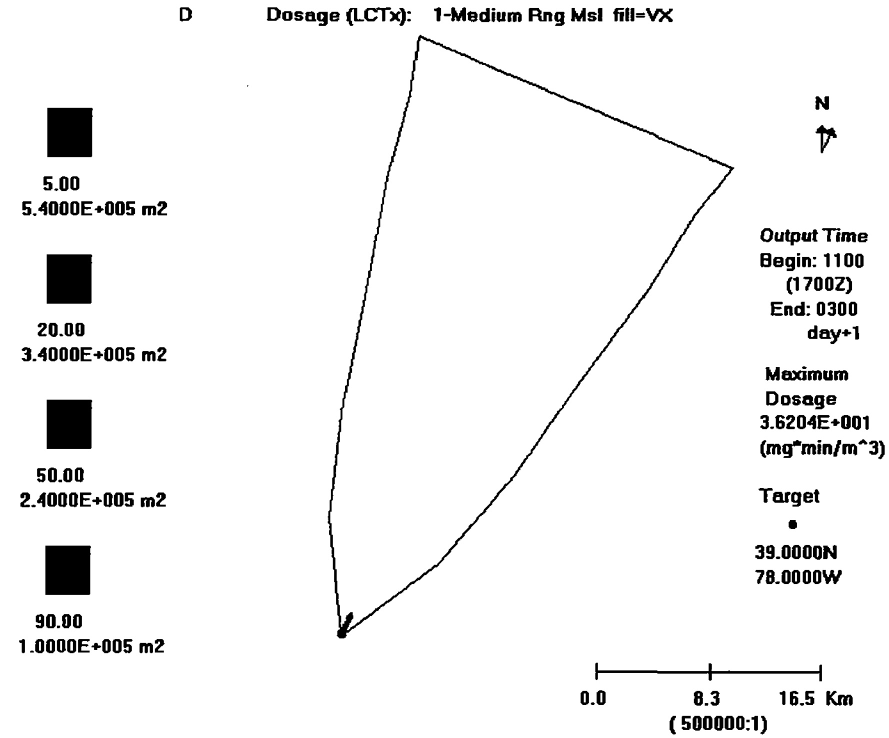
HPAC

VLSTRACK

Different scales shown

L*W =
1.41 * 0.22





At "LCt5" Estimated Area (Km^2)	HPAC [Mean Area]	VLSTRACK
	0.24 [0.35]	0.54

500 Kg OF THICKENED VX FROM A MISSILE AT 1,000 m SIMILAR SETTINGS (FIXED WIND): DOSAGE (1.8 m / 16 hr)

The chart opposite shows the VLSTRACK dosage prediction for 500 Kg of thickened VX dispensed from a ballistic missile at 1,000 meters. HPAC did not present a hazard area (AMD = 0) for this trial. However, HPAC did report a mean area of 0.03 Km^2.

Again, the small predicted VLSTRACK dosage appears to be due to secondary evaporation.

Both models predict no hazard (at the 8.2 mg-min/m^3 level – "LCt5") for the VX release at 1,000 meters and the thickened VX released at 10,000 meters

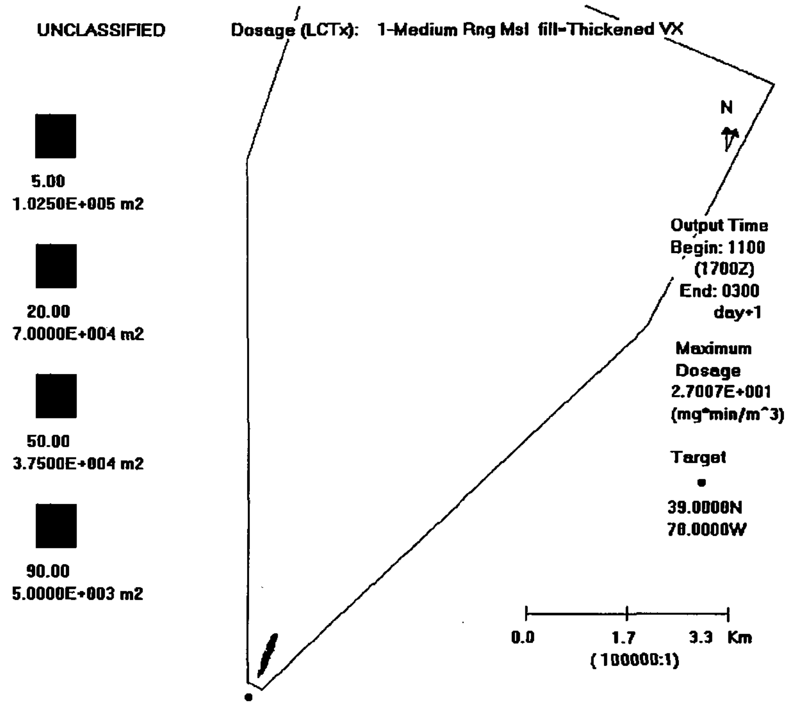
500 Kg of Thickened VX from a Missile at 1,000 m
Similar Settings (Fixed Wind): Dosage (1.8 m / 16 hr)

HPAC

VLSTRACK

Different scales shown

No dosage above HPAC "LCt5"
(8.2 mg-min/m³) presented



At "LCt5" Estimated Area (Km²)	HPAC [Mean Area]	VLSTRACK
	[0.03]	0.10

COMPARISON OF VLSTRACK AND HPAC SURFACE DEPOSITION PREDICTIONS AT "LD2" FOR DEFAULT AND SIMILAR SETTINGS

The chart opposite compares the area sizes predicted by the two models for surface deposition at 1.4 mg/m^2 – "LD2." For this scenario, in which VX or TVX was released by a ballistic missile, the most lethal effect appears to be via skin contact. Therefore, the figure at right compares the model predictions for this scenario's greatest hazard.

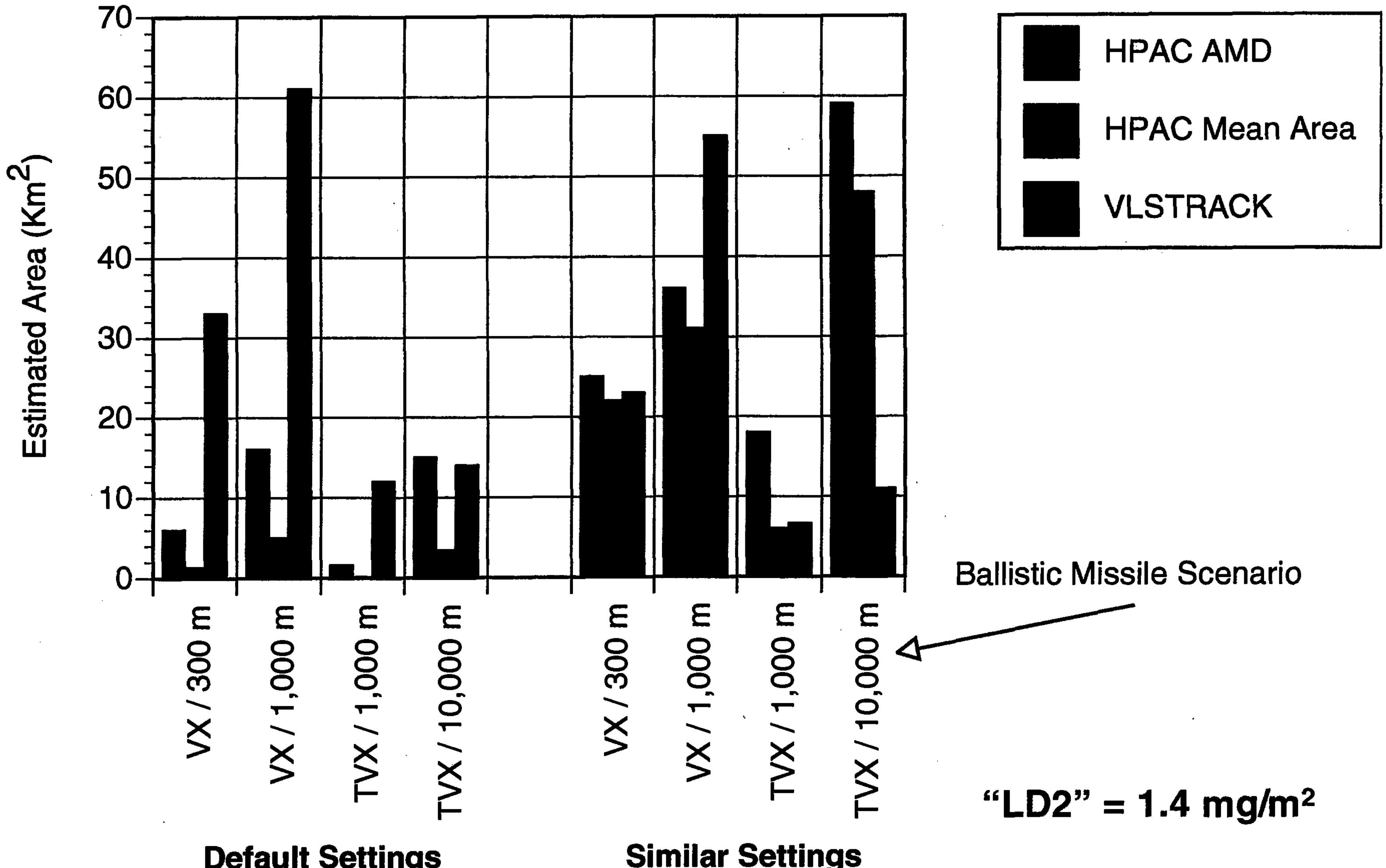
The differences in area size prediction are greatly reduced by simply standardizing the input settings. Relative to the default settings trials, the VLSTRACK area sizes shrank. Two changes were made to the inputs to create the similar settings VLSTRACK trials: the assumed wind measurement height was changed from 2 m to 10 m and the start time was moved back 1 hour. We speculate that the change in assumed wind measurement height led to slower wind speeds and hence, surface deposition over a smaller area.

Both the HPAC AMD and mean area estimates increased significantly when the similar settings were used, relative to the default settings trials. There were four changes involved in creating the similar settings inputs from the default settings for HPAC as follows:

- Source line length was changed from 300 m to 200 m.
- Fall angle was changed from 70 to 45 degrees.
- Dissemination efficiency was changed from 100 to 60 percent.
- Mass median droplet diameter (MMD) was changed from 500 μm for VX and 2,500 μm for TVX to 100 μm and 500 μm, respectively.

The analysis shown on the next slide suggests that the change in MMD was the feature that drove the large increase in area size associated with the HPAC similar settings surface deposition prediction at LD2.

Comparison of VLSTRACK and HPAC Surface Deposition Predictions at "LD2" for Default and Similar Settings



"LD2" = 1.4 mg/m^2

EFFECT OF MASS MEDIAN DROPLET DIAMETER ON HPAC'S SURFACE DEPOSITION MEAN AREA PREDICTIONS AT LD2

The figure on the right presents the HPAC-predicted mean area values for the four VX/TVX releases with four different sets of initial condition assumptions (at 16 hours). The blue bars correspond to the default settings case, and the red bars correspond to the similar settings case. Both of these have been previously described.

The MMD values assumed by HPAC, denoted MMD', are 500 and 2,500 µm for VX and TVX, respectively. VLSTRACK assumes MMD values that are one-fifth of the HPAC values (MMD'/5). Thus, for the default settings case, HPAC assumed an MMD value that was five times larger than that assumed for the similar settings case.

The green bars correspond to the area predicted by HPAC when all of the similar settings are used, with the exception of MMD. That is, for the green bars, the larger MMD, MMD' was assumed. On the other hand, the yellow bars represent the result of using all of the HPAC default settings with the exception of MMD – in this case the smaller VLSTRACK-assumed value was used, MMD'/5.

The strong implication is that the assumed MMD value greatly affected the predicted surface deposition area at LD2. In large part, the cause of the observed differences between the HPAC and VLSTRACK predicted area sizes with the default settings (at least for the 3 trials at 1,000 m and below) appears to be due to differences in MMD assumptions. This is consistent with the notion that the smaller droplets have larger surface area-to-weight ratios, and thus remain airborne longer, than the larger droplets.[44]

The differences between the HPAC predictions shown in red and yellow (and green and blue) appear to be driven by the higher assumed dissemination efficiency associated with the default trials (100 versus 60 percent).

As shown on the last slide, the difference in predicted area sizes for the 10,000-m TVX burst remains substantial between models even after incorporating the similar settings. At least a part of this difference is due to the characterization, by VLSTRACK only, of the source term as an intercept when the release is at 10,000 m. This characterization leads to a different assumed initial vapor-to-liquid ratio relative to HPAC.

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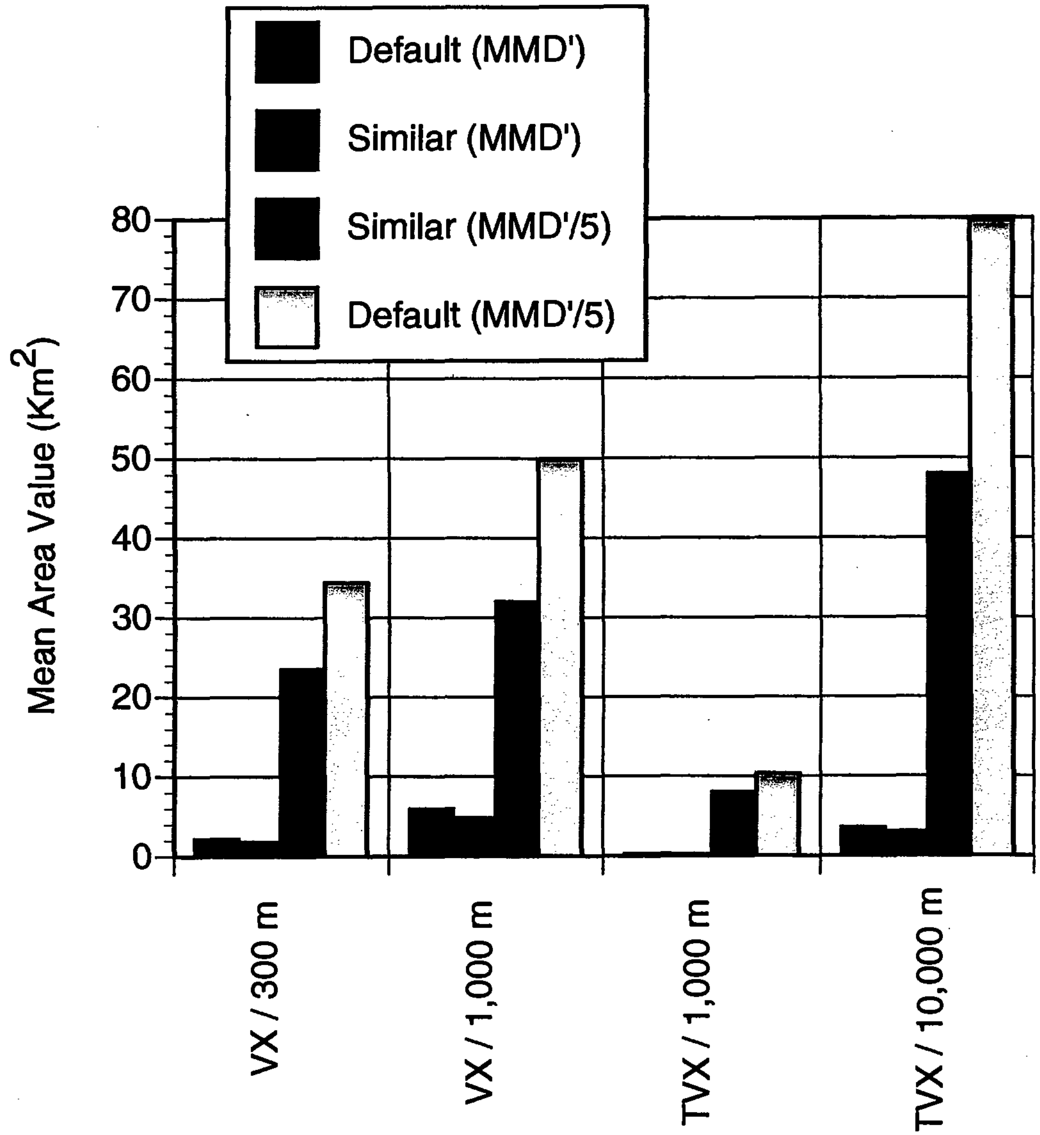
[44] For a spherical droplet, surface area increases as the square of the radius and volume – or weight for a constant density – increases as the cube of the radius. Therefore, decreasing the MMD by a factor of 5 increases the surface area-to-weight ratio by a factor of 5 ($5^3/5^2$). The increasing surface area-to-weight ratio would also be expected to increase the relative rate of evaporation, somewhat mitigating the above settling effect with respect to area coverage at a given deposition level.

Effect of Mass Median Droplet Diameter on HPAC's Surface Deposition Mean Area Predictions at LD2

MMD' (μm) = 500 for VX and 2,500 for TVX

HPAC assumes MMD'
VLSTRACK assumes MMD'/5



COMPARATIVE OBSERVATIONS FROM BIOLOGICAL WEAPON AGENT SPRAYER TRIALS

Three biological warfare agents were examined in this scenario: BWA, BWB, and BWC. Two formulations of BWA and BWB were considered for VLSTRACK: wet and dry. One thousand kilograms of the agents were released from a sprayer at 100 m to form an 800 m line. The same southern Iraq location as was investigated for the GD sprayer chemical weapon release was used.

For all three biological warfare agents that were examined, there were large differences in the predicted LCt2 area size between the two models. For BWA and BWB, the predicted HPAC area sizes at LCt2 were between about **1 and 3 orders of magnitude larger** than the reported VLSTRACK value.

The default input settings were substantially different for these biological weapon scenarios. In particular, VLSTRACK assumes an agent purity of less than 100 percent – e.g., 2 percent for "wet" BWA. In all cases, HPAC appears to assume a purity/viable agent percent of 100. In some cases, the models assumed different biological decay rates and dissemination efficiencies. For BWB and BWC, very different (factors of 3.5 and 65, respectively) amounts (in mg-min/m^3) were assumed to represent the effective or lethal dosage – the actual definitions of effective and lethal probably were different for each model.

By using similar settings – which corresponded in large part to forcing the initial release masses to be the same – the **differences in LCt2 area sizes were reduced to within a factor of about 10.**

By "shutting off" some of HPAC's fundamental features that are designed to incorporate uncertainty (large-scale variance and $T_{avg} = 0$), differences in predicted LCt2 area sizes for the less lethal agents, BWB and BWC, were further reduced to a within a factor of 2. For the highly lethal BWA – about 5 orders of magnitude by mass more lethal than BWB – the elimination of large-scale variance and low frequency turbulence components did not appreciably alter our comparative observations.

However, we found that HPAC-predicted LCt2 "0.50 probability (V>E)" areas were significantly smaller than the HPAC-predicted LCt2 mean areas and, for the BWA trials, these 0.50 probability areas were within a factor of 2 of the reported VLSTRACK mean areas.

Comparative Observations From Biological Weapon Agent Sprayer Trials

- **There were large differences in the predicted hazards from biological warfare agents**
  - For default settings, HPAC area sizes were typically 10X - 100X larger!
- **There were large differences in the default settings**
  - Assumed lethality level
  - Agent purity, dissemination efficiency, and agent decay rate
  - Using similar settings, reduced differences to a factor of about 10 or less
- **Turning off fundamental HPAC uncertainty features led to reduced differences between the models**
  - For less lethal agents (BWB and BWC), this led to predicted area size differences within a factor of 2
  - For the more lethal agent (BWA), there was no substantial change in the differences between models
  - For BWA (very low level dosage/concentration), HPAC-predicted "0.50 Prob (V>E)" area sizes were within a factor of 2 of the reported VLSTRACK "mean" values

SPRAYER AT 100 m AGL (800 m LINE): 1,000 Kg BWA (FIXED WIND = 15 Kph) DEFAULT SETTINGS DOSAGE (1.8 m)

The chart opposite presents the HPAC and VLSTRACK predictions for dosage with contours drawn at LCt2, LCt20, LCt50, and LCt90.[45] The displayed HPAC area for LCt2 is much larger than the corresponding reported VLSTRACK area. The HPAC AMD value at LCt2 is 37 and 29 times larger than the reported VLSTRACK "wet" and "dry" value, respectively. The HPAC LCt2 mean area is 12 and 9 times larger than the respective VLSTRACK values.

---

45 The ECtX values referred to in the VLSTRACK plot are identified as effective concentrations. For BWA, the assumed VLSTRACK and HPAC contour levels differ in actual dosage (in mg-min/m^3) by less than 3.3 percent.

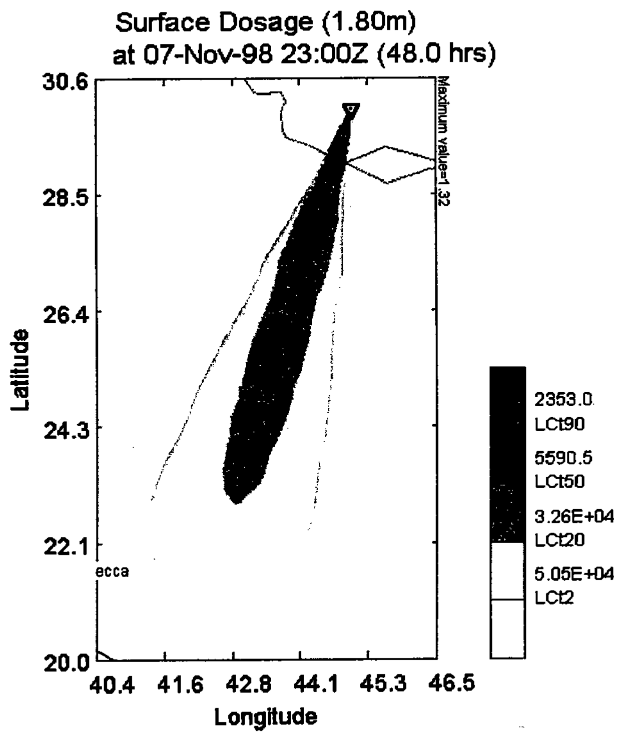
Sprayer at 100 m AGL (800 m Line): 1,000 Kg BWA (Fixed Wind = 15 Kph) Default Settings Dosage (1.8 m)

HPAC

VLSTRACK

Different scales shown

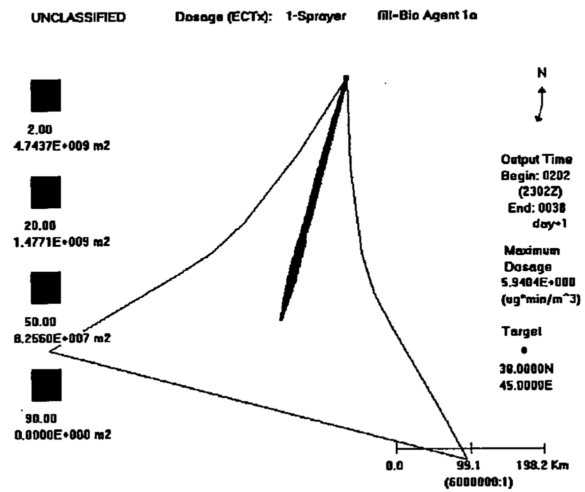
48 hr
L*W =
1,055 * 214



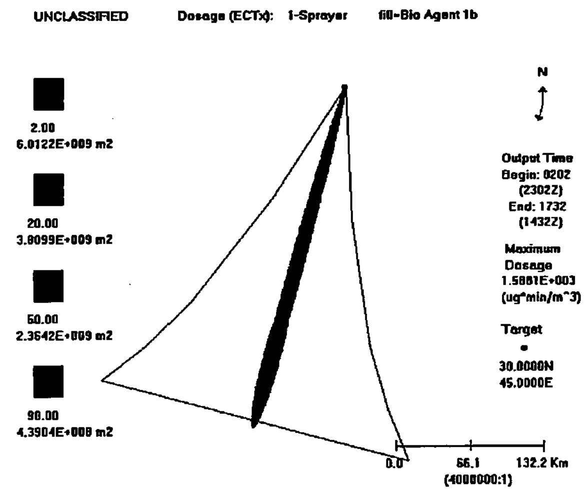
Mean population exposed at indicated level (1.00 persons/sq Km)

NOTE: Exposures based only on the displayed portion of the plume

Wet
≈ 23 hr



Dry
≈ 16 hr



At LCt2 Estimated Area (Km^2)	**HPAC** [Mean Area]	**VLSTRACK (wet/dry)**
	177,000 [55,600]	4,744/6,012

SPRAYER AT 100 m AGL (800 m LINE): 1,000 Kg BWB (FIXED WIND = 15 Kph) DEFAULT SETTINGS DOSAGE (1.8 m)

The accompanying chart presents a comparison of the predicted dosage for a release of 1,000 Kg of BWB from a sprayer. Again, the dosage reported by HPAC is longer and much fatter than the reported VLSTRACK dosage. The HPAC measures of area are much larger than the VLSTRACK reported areas.

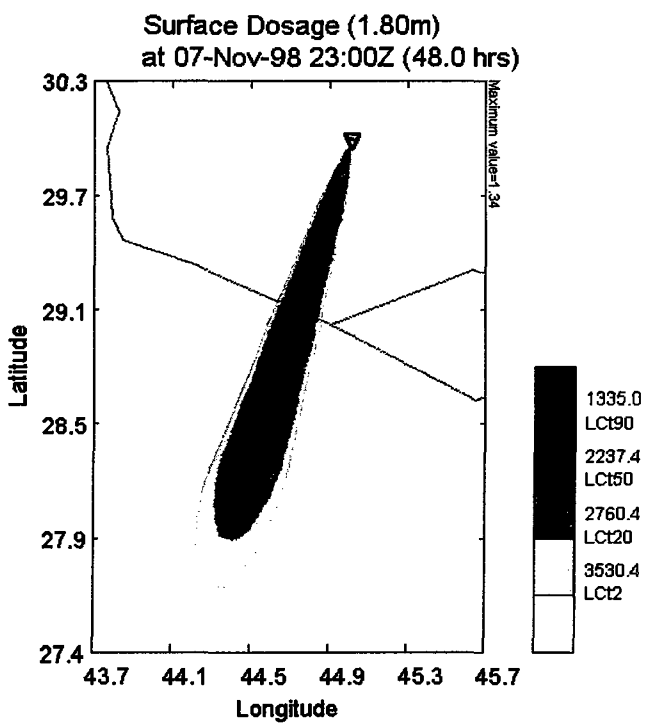
Sprayer at 100 m AGL (800 m Line): 1,000 Kg BWB (Fixed Wind = 15 Kph) Default Settings Dosage (1.8 m)

HPAC

VLSTRACK

Different scales shown

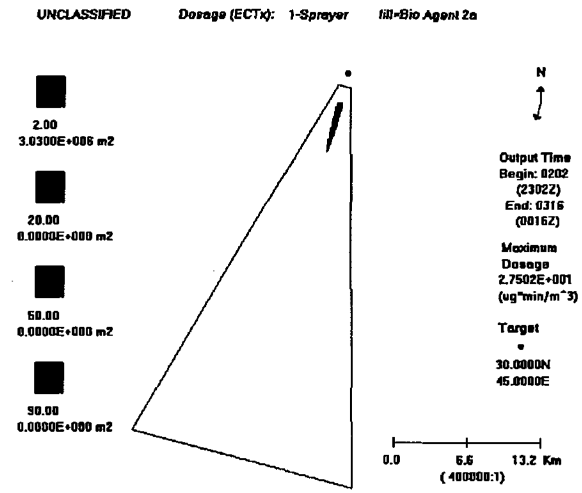
48 hr
L*W =
262 * 27



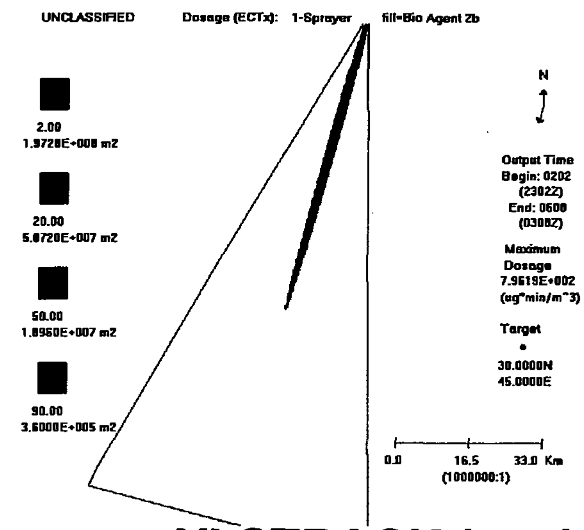
Mean population exposed at indicated level (1.00 persons/sq Km)

NOTE: Exposures based only on the displayed portion of the plume

Wet
≈ 1 hr



Dry
≈ 4 hr



At LCt2 Estimated Area (Km^2)	HPAC [Mean Area]	VLSTRACK (wet/dry)
	5,640 [3,531]	3.0/197

SPRAYER AT 100 m AGL (800 m LINE): 1,000 Kg BWC (FIXED WIND = 15 Kph) DEFAULT SETTINGS DOSAGE (1.8 m)

For the case involving the release of BWC, the HPAC predicted area sizes at LCt2 (AMD and mean area) are smaller than the reported VLSTRACK area. The VLSTRACK area size is 4.4 (relative to AMD) and 2.5 (relative to the mean area) times larger than the HPAC predictions.

Sprayer at 100 m AGL (800 m Line): 1,000 Kg BWC (Fixed Wind = 15 Kph) Default Settings Dosage (1.8 m)

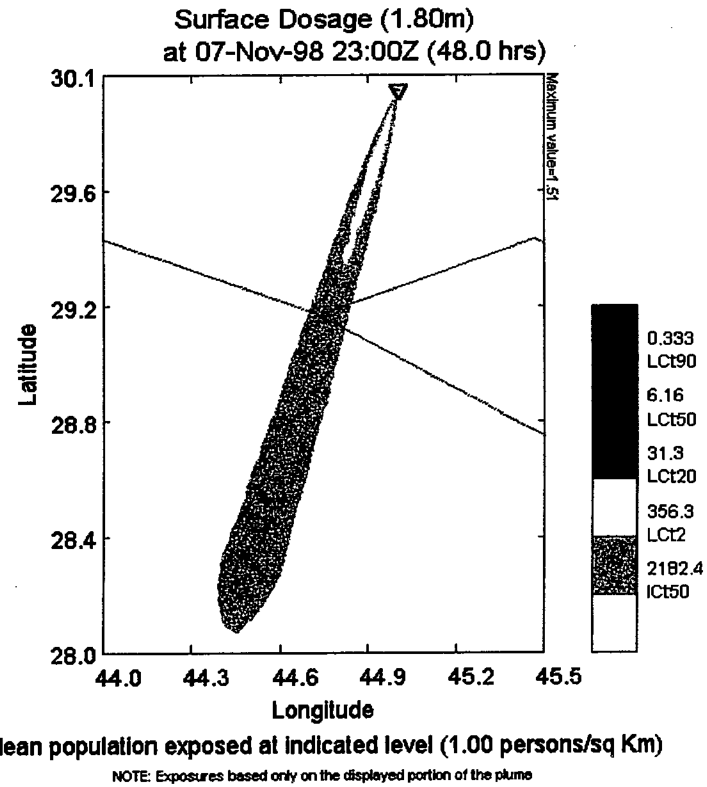
HPAC

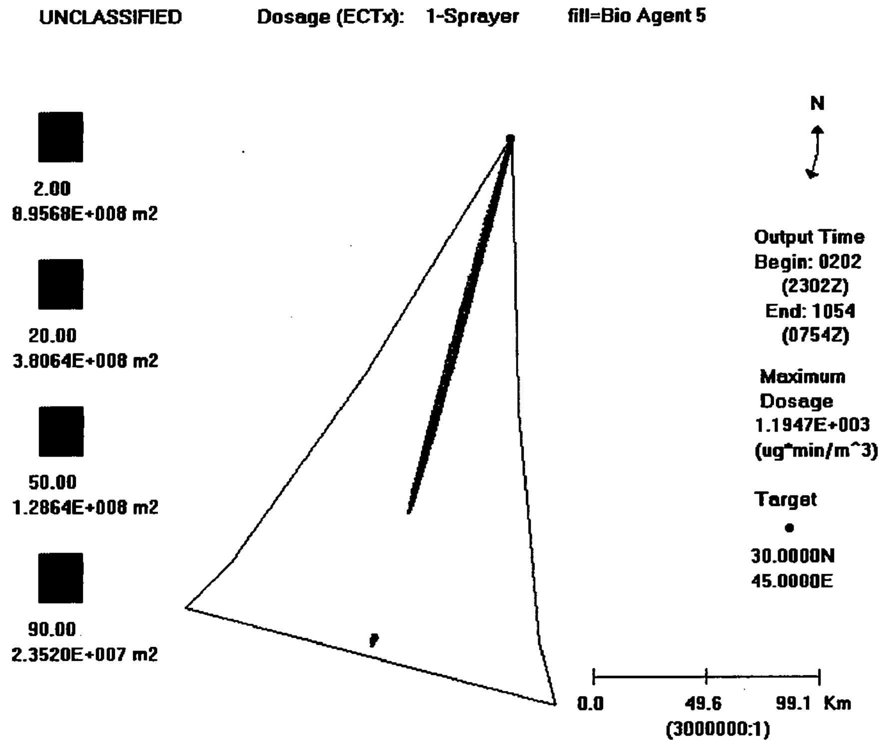
VLSTRACK

≈ 9 hr

Different scales shown

48 hr
L*W =
63 * 4





At LCt2 Estimated Area (Km^2)	HPAC [Mean Area]	VLSTRACK
	203 [356]	896

DEFAULT VS. "SIMILAR" SETTINGS FOR BIO-AGENTS FROM SPRAYER

The tables shown at right list the changes that were implemented (by overriding the default settings) to create as similar a set of initial conditions as possible. For each biological warfare agent, VLSTRACK assumed a purity of less than 100 percent that varied from 2 percent for wet BWA to 90 percent for dry BWA. In all cases, HPAC appeared to assume that all spores were viable and that the purity was 100 percent. We simulated the VLSTRACK purity/viability assumptions in HPAC by appropriately reducing the mass of the agent. The models also assume different dissemination efficiencies and daytime/nighttime biological agent decay rates. For the similar settings trials, we set the decay rates and dissemination efficiencies for the HPAC runs equal to those assumed by VLSTRACK. Other changes associated with the MMD, droplet distribution sigma, assumed wind measurement height, and initial size of the cloud (or lateral sigma) were also made where deemed appropriate (and as shown in the tables).

Default vs. "Similar" Settings for Bio-Agents from Sprayer

BWA

Model Parameters	Default (wet/dry)		"Similar" (wet/dry)	
	VLSTRACK	HPAC	VLSTRACK	HPAC
Lateral Sigma / Initial Size (m)	6	10	6	6
Dissemination Efficiency (%)	10/60	60	10/60	10/60
Mass Median Drop Diameter (µm)	3	5	3	3
Droplet Distribution Sigma (µm)	1.5	1.01	1.5	1.5
Minimum Decay Rate-Nighttime (%/min)	0.1/0.2	0.1002	0.1/0.2	0.1/0.2
Maximum Decay Rate-Daytime (%/min)	1/2	1.002	1/2	1/2
Viable Fraction / Purity (%)	2/90	100	2/90	2/90
Wind Measurement Height (m)	2	10	10	10

BWB

Model Parameters	Default (wet/dry)		"Similar" (wet/dry)	
	VLSTRACK	HPAC	VLSTRACK	HPAC
Lateral Sigma / Initial Size (m)	6	15	6	6
Dissemination Efficiency (%)	10/60	60	10/60	10/60
Droplet Distribution Sigma (µm)	1.5	1.01	1.5	1.5
Minimum Decay Rate-Nighttime (%/min)	0.4/0.8	0.1002	0.4/0.8	0.4/0.8
Maximum Decay Rate-Daytime (%/min)	3.9/7.8	1.002	3.9/7.8	3.9/7.8
Viable Fraction / Purity (%)	10/50	100	10/50	10/50
Wind Measurement Height (m)	2	10	10	10

BWC

Model Parameters	Default		"Similar"	
	VLSTRACK	HPAC	VLSTRACK	HPAC
Lateral Sigma / Initial Size (m)	6	25	6	6
Droplet Distribution Sigma (µm)	1.5	1.01	1.5	1.5
Minimum Decay Rate-Nighttime (%/min)	0.1	0	0.1	0.1
Maximum Decay Rate-Daytime (%/min)	1	0	1	1
Viable Fraction / Purity (%)	70	100	70	70
Wind Measurement Height (m)	2	10	10	10

BIOLOGICAL WARFARE AGENT TOXICITY ASSUMPTION COMPARISON

The table shown at right lists the effects assumptions for the three biological warfare agents that were considered. In one case, agent A (BWA), the assumed lethal dosages for the two models are quite similar. However, for the other two agents, there are large differences in effects assumptions. For the similar settings biological warfare agent trials, we set the HPAC lethality contours equal to those associated with VLSTRACK.

Biological Warfare Agent Toxicity Assumption Comparison

mg-min/m³

LCtX	*A*			*B*			*C*		
	HPAC	VLST	%Diff.	HPAC	VLST	%Diff.	HPAC	VLST	%Diff.
90	3.6e-2	3.5e-2	**2.9**	0.19	0.67	253	16	0.25	6300
50	5.3e-4	5.2e-4	**1.9**	4.7e-2	0.16	240	5	7.7e-2	6394
20	3.4e-5	3.3e-5	**3.0**	1.8e-2	6.3e-2	250	2.3	3.6e-2	6289
2	6.3e-7	6.1e-7	**3.3**	4.8e-3	1.6e-2	233	0.78	1.2e-2	6400

Only A appears similar!

SPRAYER AT 100 m AGL (800 m LINE): 1,000 Kg BWA (FIXED WIND = 15 Kph)
SIMILAR SETTINGS DOSAGE (1.8 m)

Relative to the default settings comparisons, the differences between the predicted HPAC and VLSTRACK dosages for BWA have been substantially reduced by using the similar input settings. The HPAC LCt2 AMD values are 5.0 and 14.7 times larger than the reported VLSTRACK values for the wet and dry cases, respectively. For the default settings case, the corresponding factors are 37 and 29. The HPAC predicted mean areas are 4.6 and 7.3 times larger than the VLSTRACK wet and dry values for this similar settings case. The corresponding factors from the default settings case are 12 and 9.

Sprayer at 100 m AGL (800 m Line): 1,000 Kg BWA (Fixed Wind = 15 Kph) Similar Settings Dosage (1.8 m)

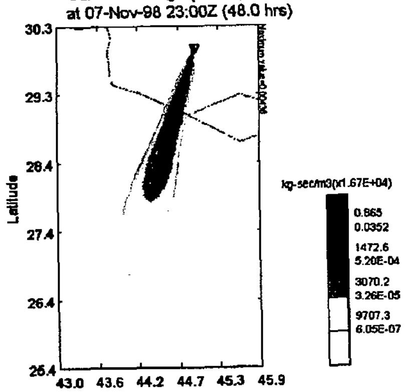
HPAC

VLSTRACK

Different scales shown

48 hr ("wet")
L*W =
365 * 47

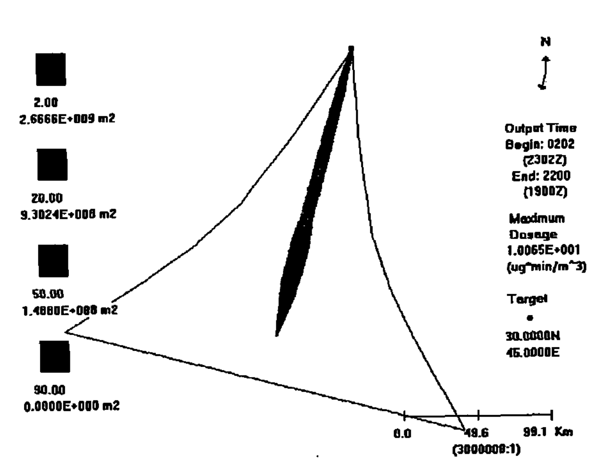
Surface Dosage (1.80m)
at 07-Nov-98 23:00Z (48.0 hrs)



Mean population exposed at indicated level (1.00 persons/sq Km)

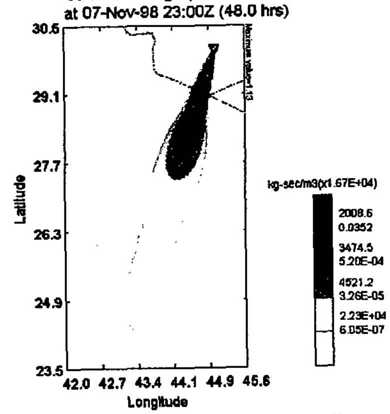
Wet
≈ 20 hr

UNCLASSIFIED Dosage (ECTx): 1-Sprayer fill-Bio Agent 1a



48 hr ("dry")
L*W =
651 * 95

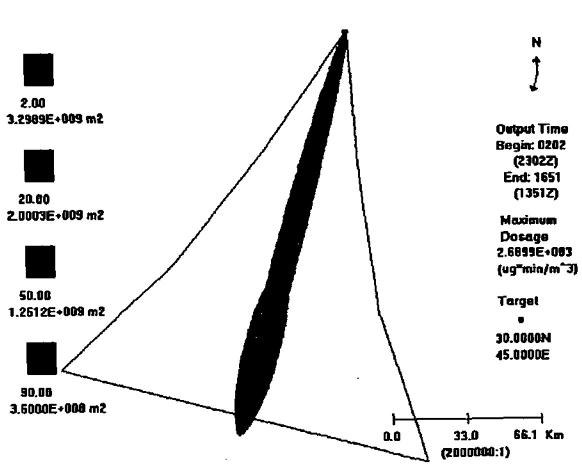
Surface Dosage (1.80m)
at 07-Nov-98 23:00Z (48.0 hrs)



Mean population exposed at indicated level (1.00 persons/sq Km)

Dry
≈ 15 hr

UNCLASSIFIED Dosage (ECTx): 1-Sprayer fill-Bio Agent 1b



At LCt2 (wet/dry) Estimated Area (Km²)	**HPAC** [Mean Area]	**VLSTRACK**
	13,342/48,598 [12,200/24,100]	2,667/3,299

SPRAYER AT 100 m AGL (800 m LINE): 1,000 Kg BWB (FIXED WIND = 15 Kph) SIMILAR SETTINGS DOSAGE (1.8 m)

For the similar settings comparison in which BWB is released by a ballistic missile, the HPAC predictions of LCt2 area size are always larger than the reported VLSTRACK areas. For the similar and default settings comparisons, the HPAC areas are larger than the reported VLSTRACK areas at LCt2 by the following factors.

- Wet BWB HPAC AMD: Similar **1.3** / Default **1,880**
- Dry BWB HPAC AMD: Similar **9** / Default **29**
- Wet BWB HPAC mean area: Similar **10** / Default **1,177**
- Dry BWB HPAC mean area: Similar **6** / Default **18**

The use of similar settings brings the predicted LCt2 areas to within one order of magnitude (a factor of 10).

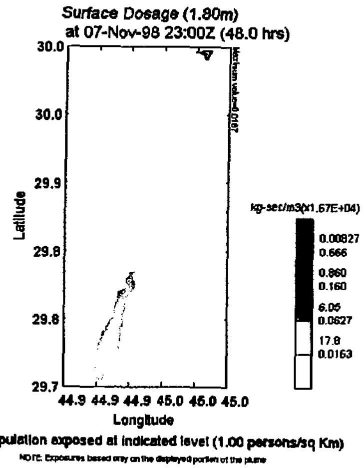
Sprayer at 100 m AGL (800 m Line): 1,000 Kg BWB (Fixed Wind = 15 Kph) Similar Settings Dosage (1.8 m)

HPAC

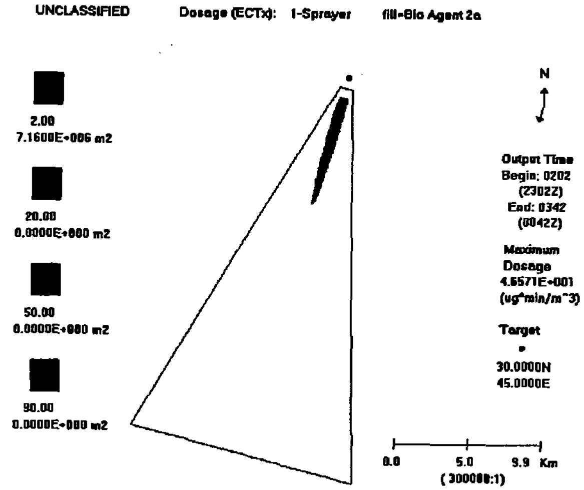
VLSTRACK

Different scales shown

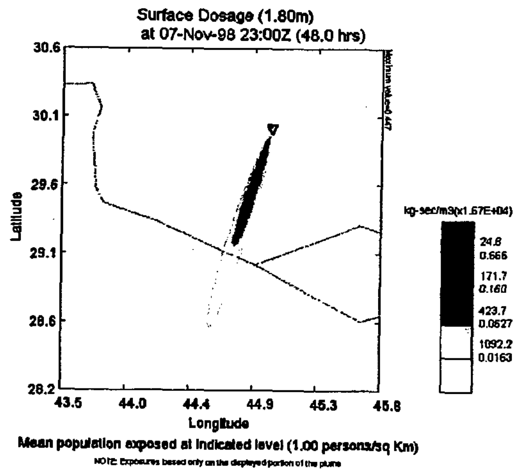
48 hr ("wet")
L*W =
9.7 * 1.2



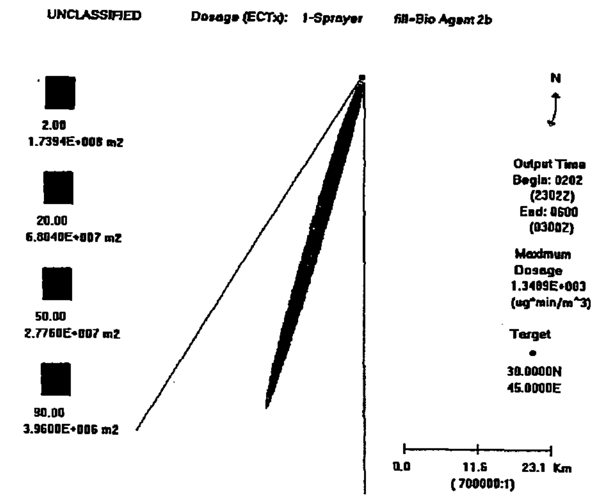
Wet
≈ **2 hr**



48 hr ("dry")
L*W =
154 * 13



Dry
≈ **4 hr**



At LCt2 (wet/dry)
Estimated Area (Km^2)

HPAC [Mean Area]
9.0/1,606 [75/1,092]

VLSTRACK
7.2/174

SPRAYER AT 100 m AGL (800 m LINE): 1,000 Kg BWC (FIXED WIND = 15 Kph)
SIMILAR SETTINGS DOSAGE (1.8 m)

For the similar settings comparison in which BWC is released, the HPAC predictions of LCt2 area size are 6.2 (AMD) and 4.6 (mean area) times the size of the reported VLSTRACK areas. For the comparable default settings case, the VLSTRACK prediction is 4.4 (AMD) and 2.5 (mean area) times the size of the HPAC LCt2 predictions.

Sprayer at 100 m AGL (800 m Line): 1,000 Kg BWC (Fixed Wind = 15 Kph) Similar Settings Dosage (1.8 m)

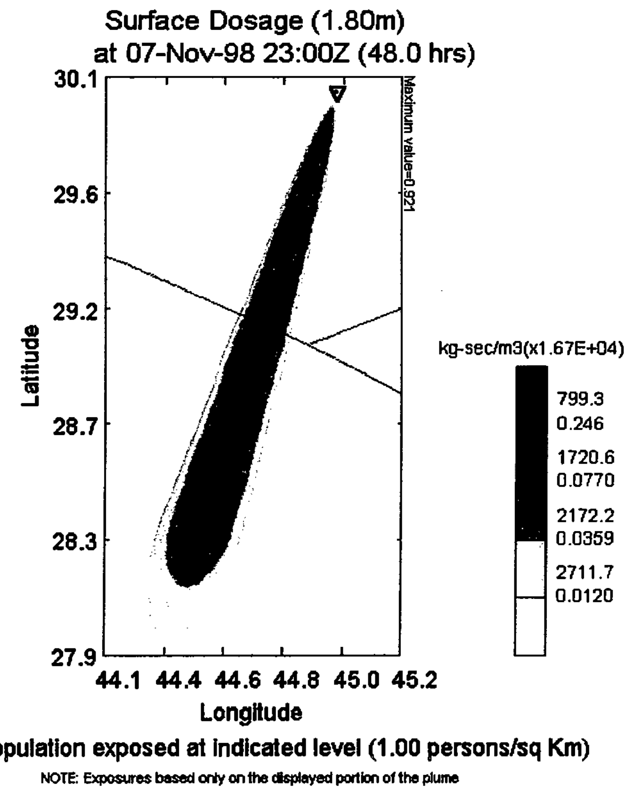
HPAC

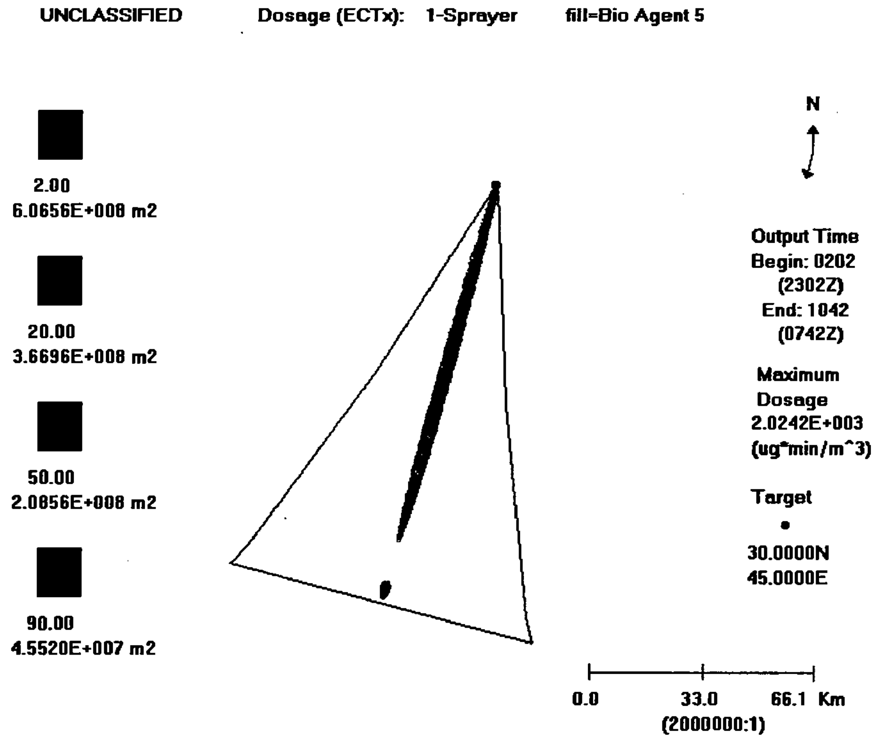
VLSTRACK

Different scales shown

≈ 9 hr

48 hr
L*W =
232 * 21





At LCt2 Estimated Area (Km²)	HPAC [Mean Area]	VLSTRACK
	3,772 [2,768]	607

COMPARISON OF DEFAULT AND SIMILAR SETTINGS PREDICTIONS

The accompanying chart compares the ratios of the predicted HPAC to reported VLSTRACK LCt2 area sizes. The ratios for both the estimated HPAC AMD (blue bars) and mean area (green bars) values are reported. For the one case in which the VLSTRACK prediction was larger, the ratio of the inverse is reported with a negative sign added. These ratios correspond to the factor that describes the size difference between the two models' predictions. For example, the figure reports that the default settings comparison in which dry BWA was released led to an HPAC AMD prediction that was almost 30 times larger than the comparable VLSTRACK prediction.

The incorporation of similar settings can be seen to reduce the differences greatly between model predictions. The remaining differences are generally within a factor of 10, always with the HPAC predictions being larger.[46]

The only change to the VLSTRACK trial in creating the similar settings case from the default settings case was to change the assumed wind measurement height. As we have seen before (in the chemical weapon scenarios), this change appears to "slow" down the cloud transport and lead to a smaller area covered at the investigated dosage contour.

The HPAC predicted area sizes for BWA and BWB are reduced relative to the default settings HPAC trial. In large part, this is caused by less material being assumed in the similar settings HPAC case (lower dissemination efficiency, higher decay rates, and less than 100 percent purity). In addition, in the case of the similar settings BWB trial, the assumed dosage required at LCt2 is about 3.5 times larger than was assumed in the comparable default settings case. For the HPAC similar settings BWC case, the predicted LCt2 area size was about 10 times larger than that associated with the comparable default settings trial. The large decrease in the assumed LCt2 required dosage level, along with the mitigating factor of a reduced dissemination efficiency, appears to have resulted in this order of magnitude increase.

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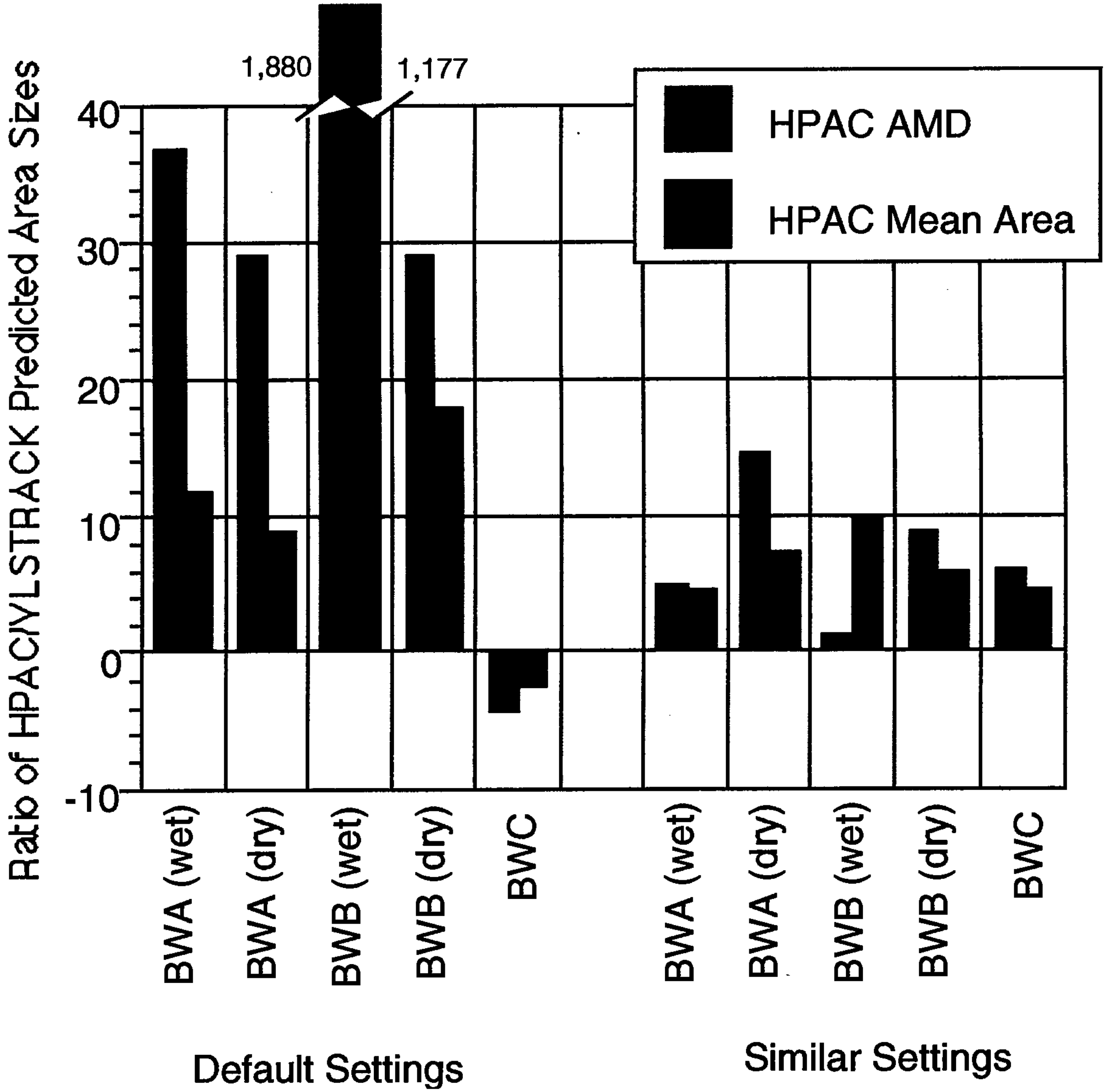
46 We also ran the VLSTRACK model with the Pasquill stability category set at very unstable ("A") for some of these biological agent trials. It was found that this could in some cases cause the VLSTRACK prediction to be wider and double to triple the associated LCt2 area size. Thus, even after adopting the most unstable PS category, by overriding what we felt was a typical operator default, and using similar settings, the VLSTRACK reported areas would be expected to differ from the HPAC predicted areas by factors up to about 5.

Comparison of Default and Similar Settings Predictions

Ratios are computed at LCt2

Negative values correspond to cases in which the VLSTRACK reported area is larger than the HPAC predicted area.



HPAC PREDICTIONS WITH THE LARGE-SCALE VARIABILITY TURNED OFF AND THE CONDITIONAL AVERAGING = 0

For long-range (> 100 Km) transport applications, HPAC includes a large-scale variability (LSV) feature. To this point, this feature was toggled to its default mode, "operational" and for these long-range biological warfare agent computations was invoked. The LSV feature is meant to account for mesoscale or synoptic scale variability in the wind field.[47]

As was the case for the previous biological warfare agent sprayer releases, the release height was 100 m.

The chart opposite compares the predictions of four different HPAC calculations for BWA released from a ballistic missile (similar settings, dry BWA case). The first figure (far left) presents the results under nominal conditions – LSV operational T_{avg} = default. This prediction corresponds to the BWA (dry) prediction shown previously. The next prediction was done with LSV turned off. The predicted dosage area (at LCt2), under these special conditions, is very long and thin relative to the nominal case. Eliminating the low frequency turbulence component ($T_{avg} = 0$) results in the next prediction.[48] For this case, the length of the dosage prediction at LCt2 is somewhat shorter, with no hazard shown near the initial release. Finally, turning off LSV and setting $T_{avg} = 0$ leads to the dosage prediction shown at the far right.

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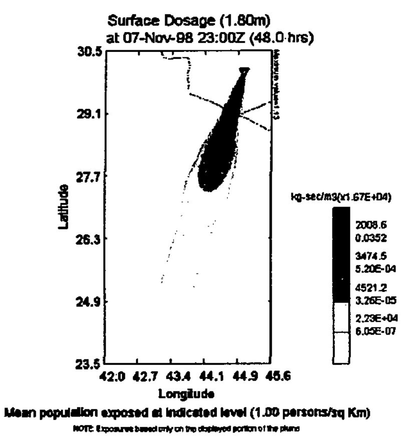
47 In the operational mode, the full effects of large-scale variability are applied when the large-scale variability length scale is exceeded by the internal puff or by the horizontal boundary layer turbulence scale. Otherwise, a simple energy spectrum assumption is used to determine the reduced variance appropriate for diffusion on scales smaller than the cloud and boundary layer scales. This description was taken from the HPAC 3.1 Help feature and more information on the details of the model used is available from that source.

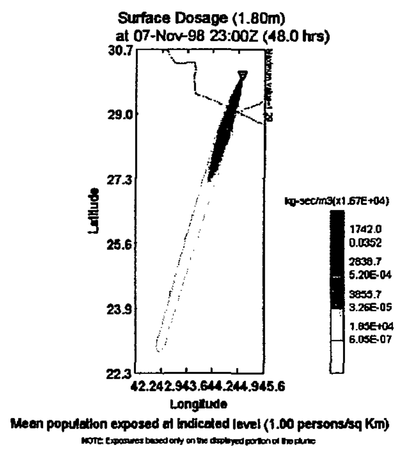
48 A more detailed discussion of T_{avg} (conditional averaging) is given in the section describing a GD release from an aerial sprayer.

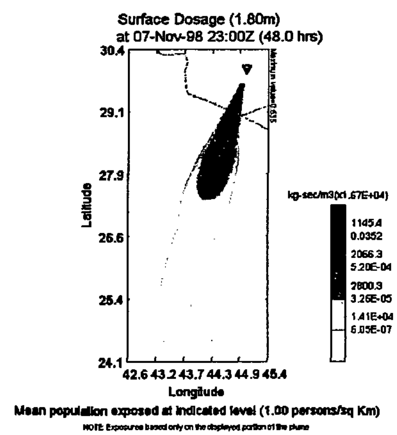
HPAC Predictions With the Large-Scale Variability Turned Off and the Conditional Averaging = 0

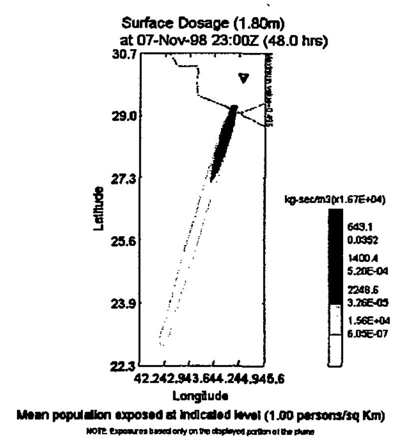
BWA (dry)
Similar Settings

L*W at LCt2 in Km	Nominal LSV and T_{avg}	LSV = None	$T_{avg} = 0$	LSV = None and $T_{avg} = 0$
	651 * 95	815 * 38	603 * 93	738 * 33









HPAC PREDICTED LCt2 AREA SIZES AS A FUNCTION OF LSV AND T_{AVG} FOR BWA

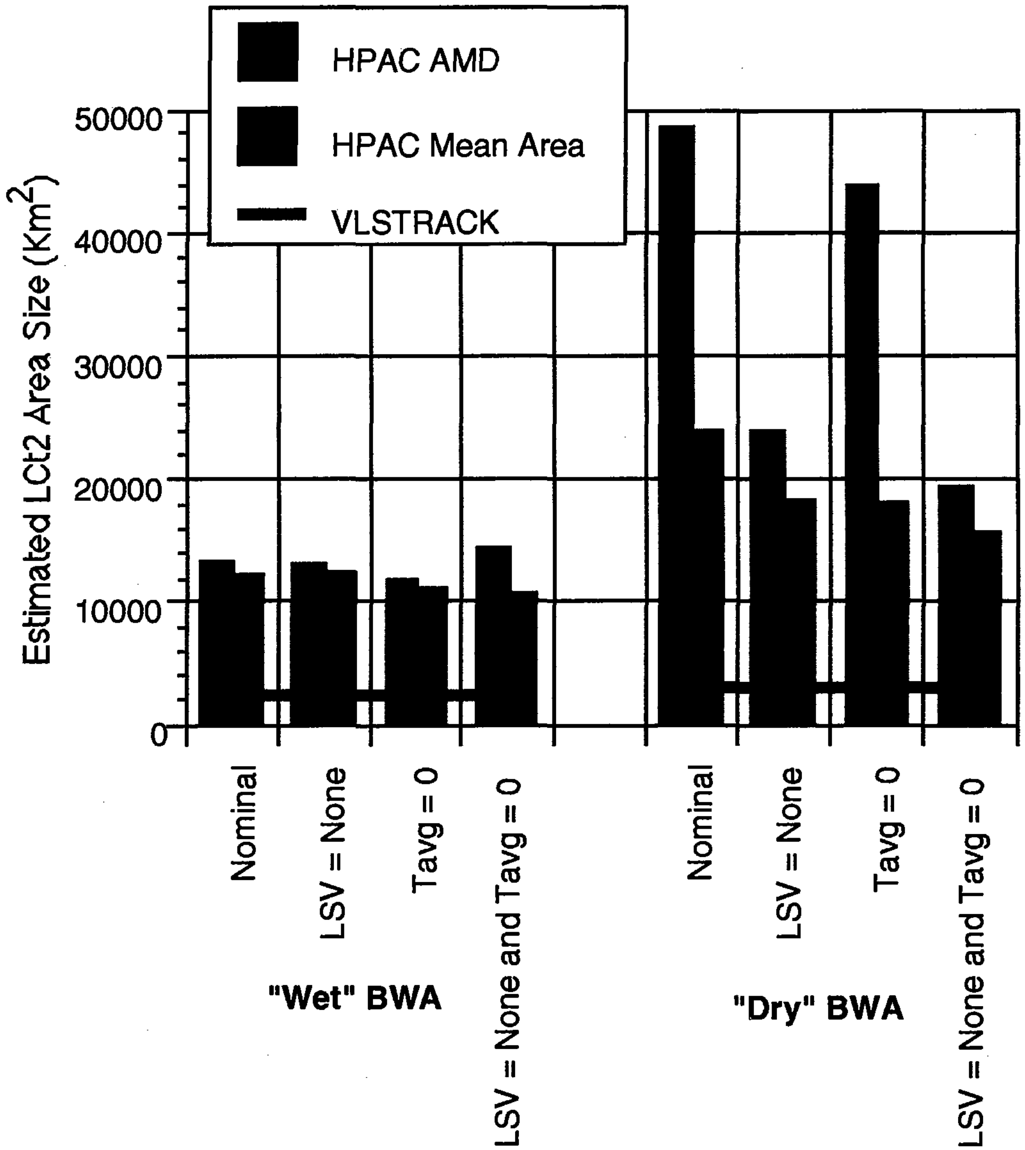
The accompanying chart provides a comparison of the HPAC predicted area sizes for the BWA trials under a variety of computational hypotheses – nominal, LSV = none, $T_{avg} = 0$, and LSV = none / $T_{avg} = 0$. The results of our calculations for the BWA wet and dry case, both under the similar settings assumptions are shown. The red line superimposed on the bar graph corresponds to the reported VLSTRACK area size for each BWA case.

For the wet BWA case, the changing computational premises appeared to have little impact on the area size predicted by HPAC (AMD or mean area). For the dry BWA case, a situation in which much more material is present, the predicted HPAC mean area is reduced a bit by eliminating LSV and setting $T_{avg} = 0$. The HPAC AMD value is greatly reduced when the LSV is removed. This may be related to the intermittent nature of the distribution that is realized when LSV is operational (as we argued in the GD sprayer case for $T_{avg} = 0$).

With respect to the VLSTRACK predictions, there is little change to our comparative observations caused by changing the computational premises. Even after eliminating LSV and low frequency turbulence and using similar settings, the HPAC predictions of LCt2 area size remain 4 to 6 times the size of the corresponding VLSTRACK reported values.

These remaining differences may be a reflection of differences between the models' simulations of transport and dispersion that are relatively unrelated to their incorporation of uncertainty (e.g., computation/incorporation of the boundary layer, assumed vertical distribution of the cloud, modeling of the vertical wind profile, and transport through the layer).

HPAC Predicted LCt2 Area Sizes as a Function of LSV and T_{avg} for BWA



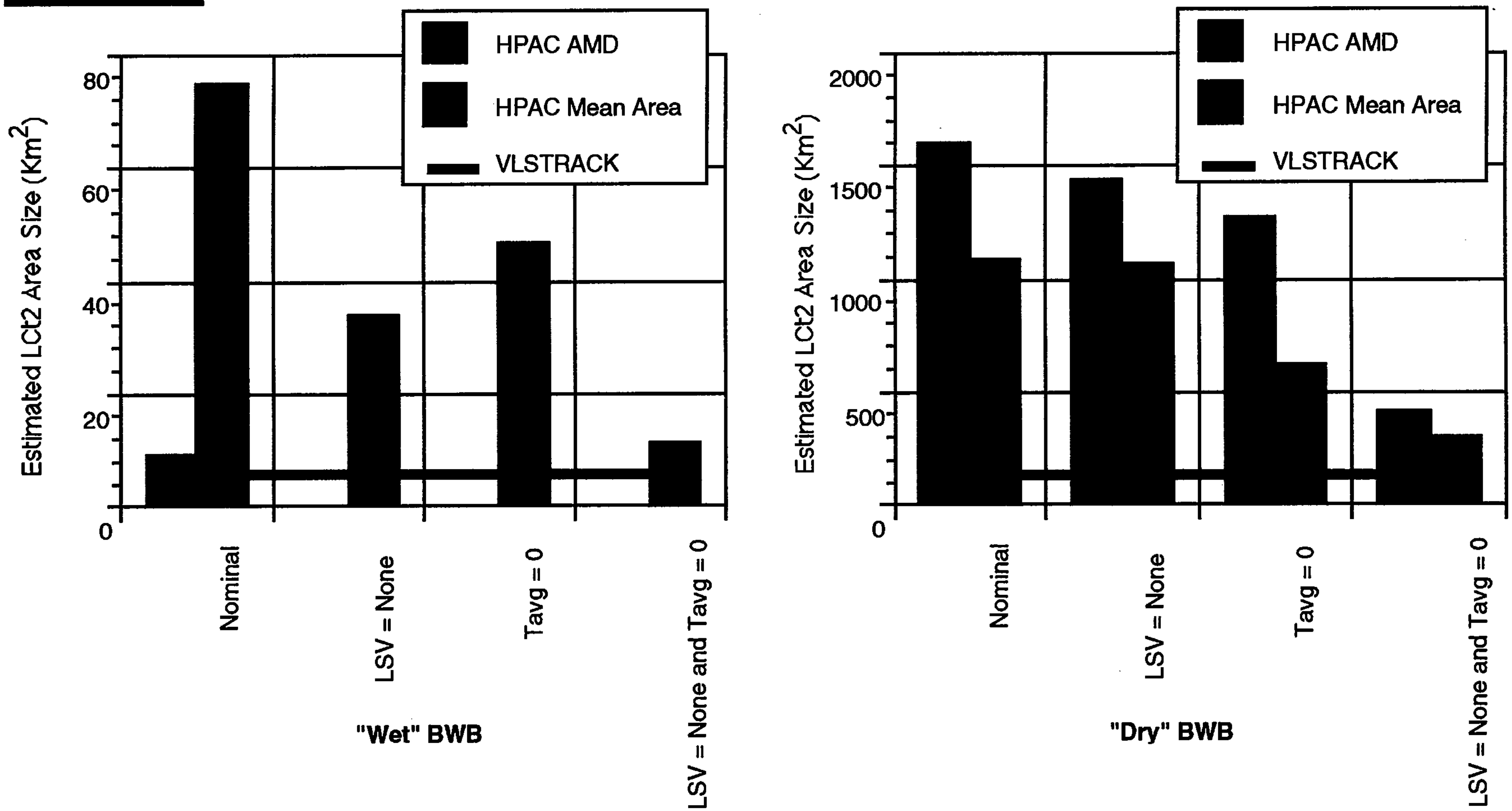
Even after shutting LSV "off" and setting T_{avg} = 0 (no low frequency turbulence component), the HPAC predictions remain 4 to 6 times the size of the VSLTRACK predictions for BWA.

HPAC PREDICTED LCt2 AREA SIZES AS A FUNCTION OF LSV AND T_{AVG} FOR BWB

The chart opposite provides comparisons similar to those described on the previous chart for BWA. In this case, the BWB release is examined. An important difference between the BWB and BWA scenarios is that BWA is 5 orders of magnitude more lethal than BWB. That is, the LCt2 contours shown for BWB require about 5 orders of magnitude more material.

For these cases, the HPAC predicted mean areas are within a factor of 2 (wet 1.5 and dry 1.7) of the reported VLSTRACK LCt2 area size.

HPAC Predicted LCt2 Area Sizes as a Function of LSV and T_{avg} for BWB



With LSV "off" and T_{avg} = 0, the HPAC BWB predicted mean areas are within a factor of 2 of the reported VLSTRACK areas.

HPAC PREDICTED LCt2 AREA SIZES AS A FUNCTION OF LSV AND T_{AVG} FOR BWC

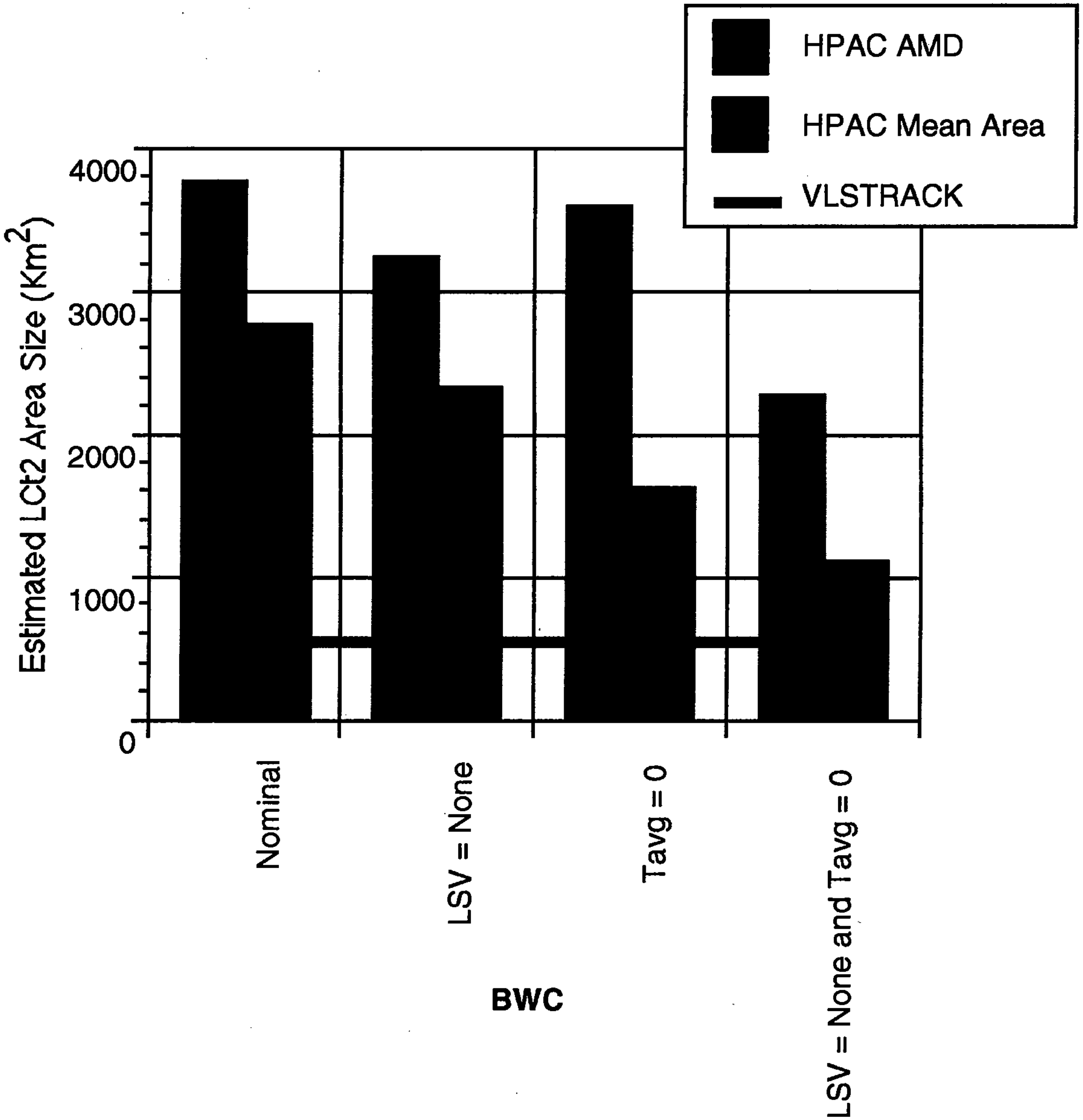
For BWC, shown on the accompanying chart, eliminating LSV and setting $T_{avg} = 0$, leads to an HPAC mean area prediction that is within a factor of 2 of the reported VLSTRACK area. We note, however, that the actual difference in area sizes between the two models for BWC is 501 Km^2.

The dosage levels associated with the BWC LCt2 contour level are similar (within one order of magnitude) of those used for BWB. Based on the last three slides, we observe the following:

- For the very low dosage levels associated with the BWA contours, the changes in computational premises had little impact on our comparative observations.
- At the higher dosage levels (BWB and BWC), elimination of LSV and the low frequency turbulence component led to predictions that were within a factor of two.

HPAC Predicted LCt2 Area Sizes as a Function of LSV and T_{avg} for BWC

With LSV "off" and T_{avg} = 0, the HPAC BWC predicted mean area is within a factor of 2 of the reported VLSTRACK area.



COMPARISON OF HPAC MEAN AREA AND "0.50 PROB (V>E)" AREA SIZE PREDICTIONS AT LCt2

The areas that are typically displayed to the user for HPAC (AMD or mean area) correspond to mean (or expected in the statistical sense) values, computed from different distributions.[49] The reported VLSTRACK area sizes also purport to correspond to mean values. HPAC, but not VLSTRACK, also allows for the calculation of the probability that a given dosage, for instance, is exceeded. From these calculations, contours can be drawn at given probability levels – P(V>E). This value is reported in red by HPAC, when the "Probability (V>E)" toggle is used. This value corresponds to the area size contained by the contour in which the population would be exposed to LCtX with risk p_i (for example, 0.50) or greater.

The bar graph (opposite) compares the HPAC predicted mean and 0.50 Prob (V>E) area sizes. For this particular case, the mean and 0.50 Prob (V>E) values differ greatly. In fact, whereas the mean area values were 4 to 5 times larger than the reported VLSTRACK area size at LCt2, the 0.50 Prob (V>E) area sizes are within a factor of 2, for the BWA trials.

The predicted HPAC mean and 0.50 Prob (V>E) areas and the ratios of these areas to the reported VLSTRACK areas are listed in the accompanying table. In several cases the mean and 0.50 Prob (V>E) HPAC area size predictions are quite similar. However, for the lower level dosages (ANT), and when LSV and T_{avg} are set at their default settings, the mean area size reported can be quite a bit larger than the 0.50 Prob (V>E) area.

The relationship between the HPAC predicted mean and 0.50 Prob (V>E) areas (values reported in red) is a complicated function of the shape (in 2-dimensions) of the distribution from which they arise. Of course, distributions with long "tails" can generate mean values that correspond to very high percentile results (e.g., 95th or greater). Typical operational users may not recognize the full scope of this potential difference nor have a good sense for which conditions necessarily lead to long "tails." **We imagine that for many users, the communication of the hazard area via a percentile may have improved operational utility.** For HPAC, this capability seems possible, and may in part, be a motivating factor for the recent incorporation of the "hazard area" feature.

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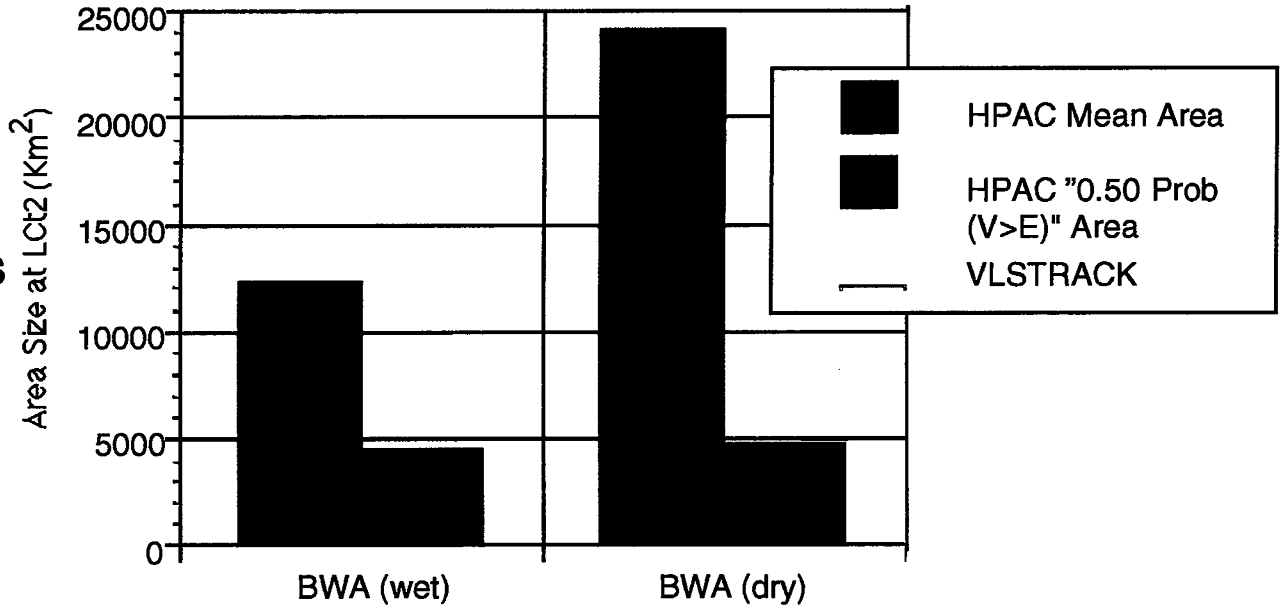
49 The AMD (area of the mean dosage) is based on the **displayed area** and is computed from the mean dosage field The mean area value corresponds to the area reported by HPAC **in red** as the "Mean Population Exposed" for an assumed density of 1 person per Km^2. For each realization of the turbulent wind field, a set of dosage values at each grid point (d{x,y}) can be computed. From this dosage field, a dosage area at a specified value can be estimated. The average of these dosage areas, computed in this way over all of the turbulent wind fields considered, is defined here as the mean area.

Comparison of HPAC Mean Area and "0.50 Prob (V>E)" Area Size Predictions at LCt2

Similar Settings Trials



Trial	*LSV/ T...*	*HPAC Mean Area*	*HPAC 0.50 P(V>E) Area*	*VLS*	*Ratio Mean Area*	*Ratio 0.50 P(V>E) Area*
BWA wet	def/def	12,200	**4,392**	2,677	4.6	**1.6**
BWA wet	off/0	10,800	**10,900**	2,677	4.0	**4.1**
BWA dry	def/def	24,100	**4,643**	3,299	7.3	**1.4**
BWA dry	off/0	15,600	**15,900**	3,299	4.7	**4.8**
BWB wet	def/def	75	**0**	7.2	10.4	**-**
BWB wet	off/0	11	**0**	7.2	1.5	**-**
BWB dry	def/def	1,092	**920**	174	6.3	**5.3**
BWB dry	off/0	301	**194**	174	1.7	**1.1**
BWC	def/def	2,768	**2,486**	607	4.6	**4.1**
BWC	off/0	1,108	**1,041**	607	1.8	**1.7**

COMPARATIVE OBSERVATIONS FROM BIOLOGICAL WEAPON AGENT BALLISTIC MISSILE WITH SUBMUNITIONS TRIALS

This trial examined the release BWA (dry), BWB (dry), and BWC from 50 submunitions delivered by a ballistic missile. The same South Korean location as was used for the GB artillery chemical weapon release was examined. The environment for this trial was assumed to be grassland with overcast skies. Both a fixed wind – 6 Kph out of the north-northwest (350 degrees) – and two simple curved winds were considered for this comparative study.

For all three biological warfare agents that were examined, there were large differences in the predicted LCt2 area size between the two models. For BWA and BWB, the predicted default settings HPAC mean area sizes at LCt2 were factors of 17 and 7 larger than the reported VLSTRACK value, respectively. For the case in which BWC was released, the VLSTRACK default settings prediction was 72 times larger than the corresponding HPAC prediction.

The default settings were substantially different for these biological weapon scenarios. The two models appeared to assume different masses per submunition, different dissemination efficiencies, different agent purity, and different decay rates, and, as described earlier, very different levels of lethality/effectiveness for BWB and BWC.

By using similar settings, the differences in LCt2 area sizes were reduced to within a factor of about 2 for BWB and BWC. However, for the highly lethal (i.e., low dosage required) BWA, large differences (factor of 12) in predicted mean area sizes at LCt2 remained.

We also examined the release of BWA (dry) with the assumptions of simple curved winds and similar settings. Again, the HPAC LCt2 mean area prediction was substantially larger than the reported VLSTRACK area (factors of about 4). Eliminating some fundamental HPAC uncertainty features (i.e., setting T_{avg} = 0 and LSV = none) reduced the differences between the HPAC and VLSTRACK predictions to within a factor of about 2, with the HPAC prediction at LCt2 still encompassing a larger area.

Finally, we included a more complicated, HPAC-generated "historical" weather profile and used the HPAC terrain incorporation feature and reran the case that involved the release of BWA (dry) via 50 submunitions. Similar features were not available in VSLTRACK 1.6.3. The incorporation of historical weather and terrain, not unexpectedly, led to significantly different predictions of hazard location.

Comparative Observations From Biological Weapon Agent Ballistic Missile With Submunitions Trials

- **There were large differences in the predicted hazards from biological warfare agents**
  - For default settings, HPAC area sizes were 17X and 7X larger for BWA and BWB
  - For default settings, VLSTRACK area size was 72X larger for BWC
- **There were large differences in the default settings**
  - Assumed lethality level (BWB and BWC)
  - Agent purity, dissemination efficiency, and agent decay rate
  - Using similar settings, reduced differences to a factor of less than about 2 for BWB and BWC but had only minimal variance reducing effect on BWA predictions
- **Assuming simple curved winds led to similar observations**
- **Incorporation of more realistic winds and terrain can have a large effect on hazard predictions**

RELEASE OF BIOLOGICAL WARFARE AGENTS FROM A BALLISTIC MISSILE: (FIXED WIND = 6 Kph) DEFAULT SETTINGS DOSAGE (1.8 m)

The accompanying chart presents comparisons of the predicted HPAC and VLSTRACK dosages for the release, separately, of three biological warfare agents from a ballistic missile with 50 submunitions. For this default settings case, there are significant differences in the predictions of the two models.

The shape and size of the HPAC-predicted LCt2 BWA (dry) area is quite different from that reported by VLSTRACK. As we have seen before, the HPAC-predicted area is wider (crosswind) and much larger (by a factor of 17 for the mean area).

The HPAC BWB LCt2 mean area size is a factor of 7 times larger than the corresponding reported VLSTRACK value. For BWC, the VLSTRACK ECt2 area size is larger (by a factor of 72) than the HPAC-predicted LCt2 mean area. These results are consistent with those described for the sprayer release of biological warfare agents.

Differences in the initial source representation may be apparent for BWB and BWC. The initial assumed spread of the 50 submunitions appears somewhat larger for HPAC than for VLSTRACK.[50]

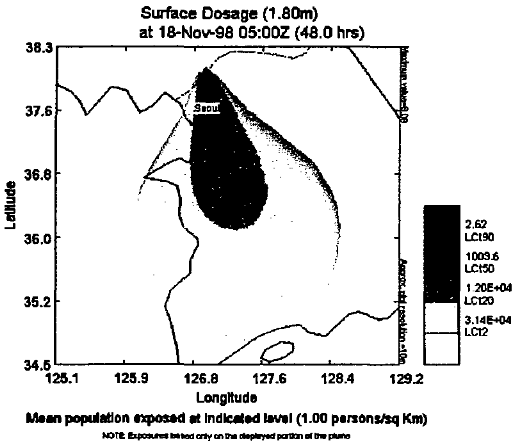
50 We varied this "initial spread" parameter a bit and found that are conclusions were unchanged.

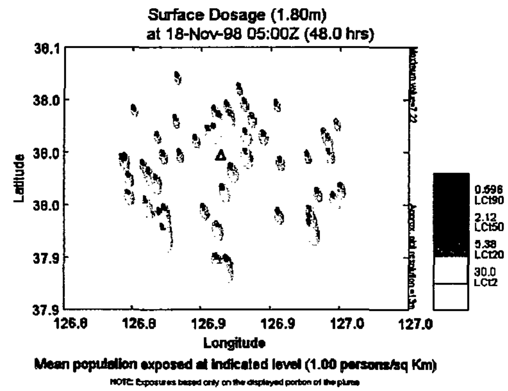
Release of Biological Warfare Agents from a Ballistic Missile: (Fixed Wind = 6 Kph) Default Settings Dosage (1.8 m)

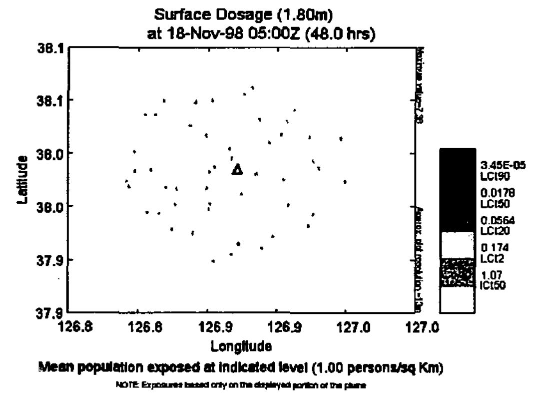
	BWA	BWB	BWC

Different scales shown

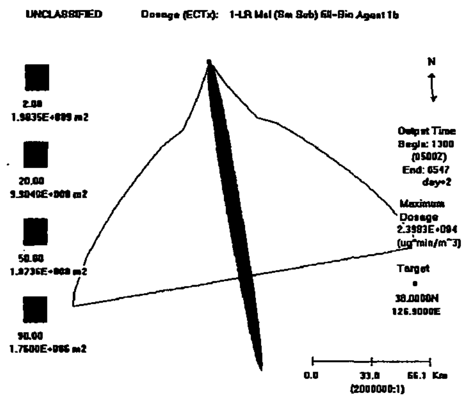
HPAC

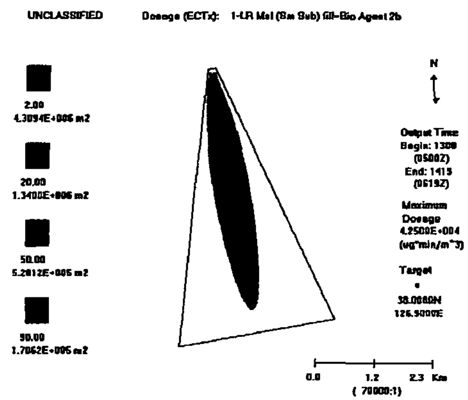


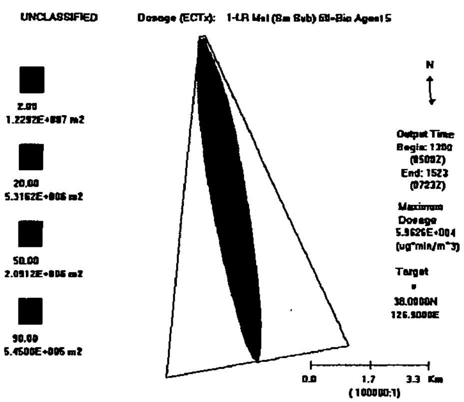




VLSTRACK







At E/LCt2 (BWA/BWB/BWC) Estimated Area (Km^2)	**HPAC** [Mean Area]	**VLSTRACK**
	61,478/na/na [33,500/30/0.17]	1,983/4.3/12.3

DEFAULT VS. "SIMILAR" SETTINGS FOR BIO-AGENTS FROM BALLISTIC MISSILE WITH 50 SUBMUNITIONS

The tables shown on the accompanying slide describe the changes that were made to the default settings to create the similar settings initial conditions. The biggest changes that were made are associated with effects assumptions, the mass of viable material that is released – mass per round and purity – and the biological agent decay rates.

In addition to the changes shown above, we also adjusted the HPAC submunition spread. The default value was 8,000 m. For a long-range ballistic missile with 50 submunitions, VLSTRACK used "downrange and crossrange target standard deviations" of 999 m. After some trial and error, we found that using an HPAC spread of about 500 m gave similar initial conditions in terms of the spread of the 50 submunitions. Therefore, for the similar settings trials we used an HPAC submunition spread of 500 m.

Default vs. "Similar" Settings for Bio-Agents from Ballistic Missile With 50 Submunitions

BWA (dry) Model Parameters	*Default*		*"Similar"*	
	VLSTRACK	HPAC	VLSTRACK	HPAC
Mass Per Submunition (Kg)	3	1.56	3	3
Height of Release (m)	0	2	0	0
Lateral Sigma / Initial Size (m)	4	5	4	4
Dissemination Efficiency (%)	3	5	3	3
Mass Median Drop Diameter (µm)	3	5	3	3
Droplet Distribution Sigma (µm)	1.5	1.01	1.5	1.5
Minimum Decay Rate-Nighttime (%/min)	0.2	0.1002	0.2	0.2
Maximum Decay Rate-Daytime (%/min)	2	1.002	2	2
Viable Fraction / Purity (%)	90	100	90	90
Wind Measurement Height (m)	2	10	10	10

BWB (dry) Model Parameters	*Default*		*"Similar"*	
	VLSTRACK	HPAC	VLSTRACK	HPAC
Mass Per Submunition (Kg)	3	1.56	3	3
Height of Release (m)	0	2	0	0
Lateral Sigma / Initial Size (m)	4	5	4	4
Dissemination Efficiency (%)	3	5	3	3
Droplet Distribution Sigma (µm)	1.5	1.01	1.5	1.5
Minimum Decay Rate-Nighttime (%/min)	0.8	0.1002	0.8	0.8
Maximum Decay Rate-Daytime (%/min)	7.8	1.002	7.8	7.8
Viable Fraction / Purity (%)	50	100	50	50
Wind Measurement Height (m)	2	10	10	10

BWC Model Parameters	*Default*		*"Similar"*	
	VLSTRACK	HPAC	VLSTRACK	HPAC
Mss Per Submunition (Kg)	3	1.56	3	3
Height of Release (m)	0	2	0	0
Lateral Sigma / Initial Size (m)	4	5	4	4
Droplet Distribution Sigma (µm)	1.5	1.01	1.5	1.5
Dissemination Efficiency (%)	3	5	3	3
Minimum Decay Rate-Nighttime (%/min)	0.1	0	0.1	0.1
Maximum Decay Rate-Daytime (%/min)	1	0	1	1
Viable Fraction / Purity (%)	70	100	70	70
Wind Measurement Height (m)	2	10	10	10

RELEASE OF BIOLOGICAL WARFARE AGENTS FROM A BALLISTIC MISSILE: (FIXED WIND = 6 Kph) SIMILAR SETTINGS DOSAGE (1.8 m)

For the case of similar settings, the relative area sizes predicted for the BWA (dry) release are still substantially different. That is, the HPAC mean area is about 12 times the size of the corresponding VLSTRACK area.

Relative to the default settings case, the VLSTRACK similar settings BWA (dry) case led to a smaller area size. This was caused by the change in assumed wind measurement height as described previously. The HPAC area also shrunk relative to the default settings HPAC prediction. In this case, the actual assumed default settings mass (50 rounds × 1.56 Kg/per round × 100% purity × 5% dissemination efficiency = 3.90 Kg) and similar settings mass (50 rounds × 3 Kg/per round × 90% purity × 3% dissemination efficiency = 4.05 Kg) were about the same. The change in predicted area size appears to be driven by the doubling in the assumed biological warfare agent decay rate.

For BWB and BWC, similar changes in decay rate and substantial changes in the assumed lethality (to be consistent with the VLSTRACK assumptions) led to a decrease in the HPAC-predicted LCt2 BWB area and an increase in the HPAC-predicted LCt2 BWC area. **With the use of similar settings, the predictions of VLSTRACK and HPAC fall within a factor of about 2 of each other for BWB and BWC.**[51]

The comparative observations from the two biological agent releases that we examined – sprayer and ballistic missile – appear relatively consistent.

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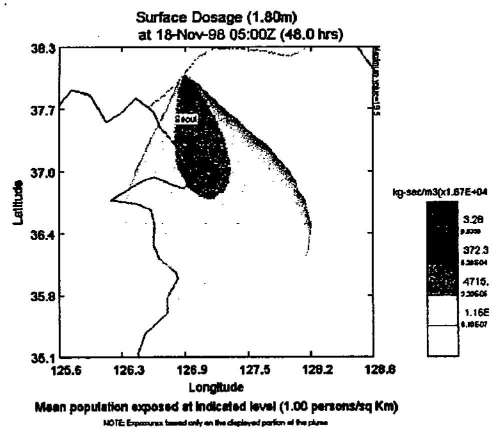
[51] We also ran this scenario with the similar settings but with the exception of the HPAC submunition spread being left at its default value – 8,000 m. Although it was obvious from the plots that this led to different initial submunition distributions between VLSTRACK and HPAC, comparisons of the measures of interest here, LCt2 area size, were relatively unaffected. For example, the HPAC LCt2 mean area sizes were 16,600, 2.7, and 6.6 Km^2 for the BWA, BWB, and BWC cases, respectively.

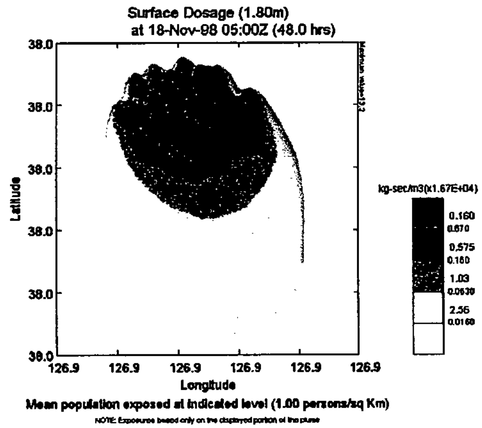
Release of Biological Warfare Agents from a Ballistic Missile: (Fixed Wind = 6 Kph) Similar Settings Dosage (1.8 m)

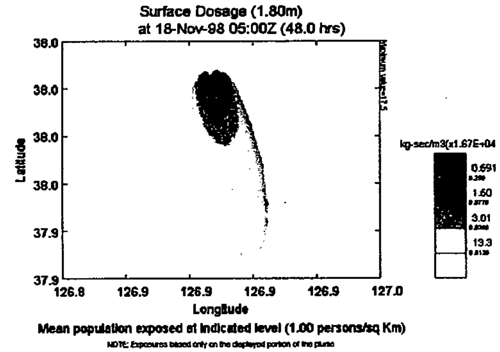
BWA **BWB** **BWC**

Different scales shown

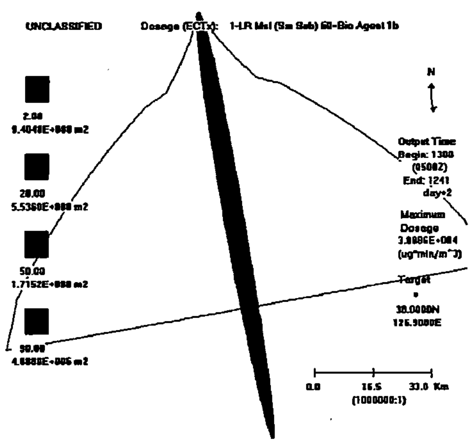
HPAC

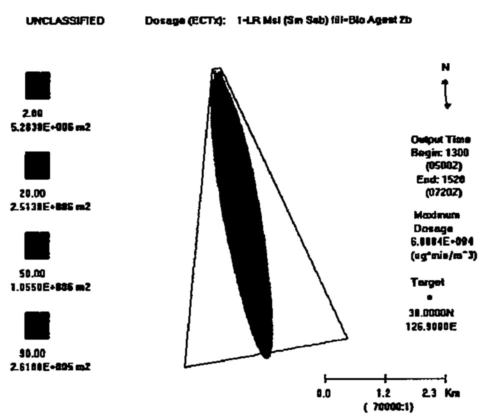


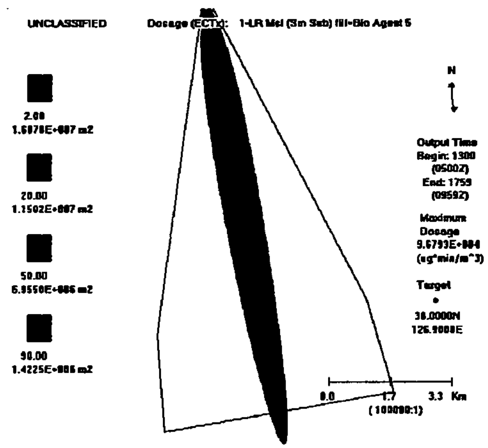




VLSTRACK







At E/LCt2 (BWA/BWB/BWC) Estimated Area (Km^2)	**HPAC** [Mean Area]	**VLSTRACK**
	34,427/2.9/13.1 [11,700/2.6/13.6]	940/5.3/16.9

SIMPLE TIME VARIABLE WIND

To this point, we have considered simple fixed winds only. The table at right presents the time-variable winds that were examined. The ballistic missile (with 50 submunitions) release of BWA (dry) using the similar settings was investigated with the application of the two time-variable winds (A and B) shown at right. Both winds correspond to curved trajectories with the wind changed from 350 degrees to 235 degrees over 24 hours. For wind A, the wind speed starts at 15 Kph, slows continuously and uniformly to 5 Kph, and then speeds up to 31 Kph. For wind B, a similar set of changes leads to a minimum wind speed of 2 Kph and a final (at 24 hours) wind speed of 22 Kph.

Simple Time Variable Winds

Wind A | Wind B

(Speed in Kph, Bearing in deg)

Time	Spd	Brg	Time	Spd	Brg	Time	Spd	Brg	Time	Spd	Brg
1	15	350	**13**	9	290	**1**	15	350	**13**	3	290
2	14	345	**14**	11	285	**2**	14	345	**14**	2	285
3	13	340	**15**	13	280	**3**	13	340	**15**	4	280
4	12	335	**16**	15	275	**4**	12	335	**16**	6	275
5	11	330	**17**	17	270	**5**	11	330	**17**	8	270
6	10	325	**18**	19	265	**6**	10	325	**18**	10	265
7	9	320	**19**	21	260	**7**	9	320	**19**	12	260
8	8	315	**20**	23	255	**8**	8	315	**20**	14	255
9	7	310	**21**	25	250	**9**	7	310	**21**	16	250
10	6	305	**22**	27	245	**10**	6	305	**22**	18	245
11	5	300	**23**	29	240	**11**	5	300	**23**	20	240
12	7	295	**24**	31	235	**12**	4	295	**24**	22	235

RELEASE OF BWA FROM A BALLISTIC MISSILE: (TIME-VARIABLE WIND) SIMILAR SETTINGS DOSAGE (1.8 m)

The figures shown on the accompanying chart provide a comparison of the predicted HPAC and VLSTRACK dosages for the case of a BWA (dry) release from a ballistic missile with 50 submunitions (using similar settings). Two different curved winds were assumed – wind A and wind B; the "similar" settings, as described earlier, were used. The HPAC-predicted LCt2 areas are larger than those reported by VLSTRACK.[52]

For wind A, the HPAC LCt2 area is a factor of 3.9 larger than the reported VLSTRACK value. The corresponding HPAC/VLSTRACK ratio for the wind B condition is also 3.9.

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52 The assumed HPAC submunition spread was 500 m for these trials. We also considered an initial HPAC submunition spread of 8,000 m. Overall, our comparative results were similar. For the 8,000 m initial spread, the HPAC-predicted mean areas for wind A and B were 29,200 and 19,800 Km^2 at LCt2, respectively

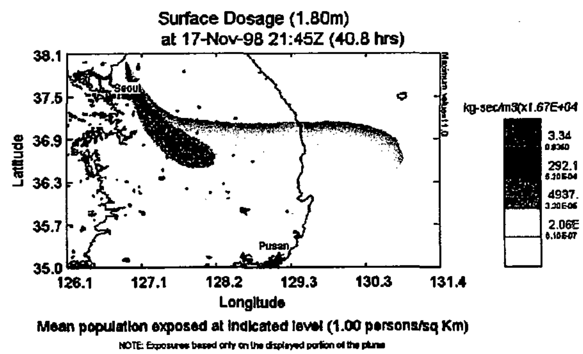
Release of BWA from a Ballistic Missile: (Time-Variable Wind)
Similar Settings Dosage (1.8 m)

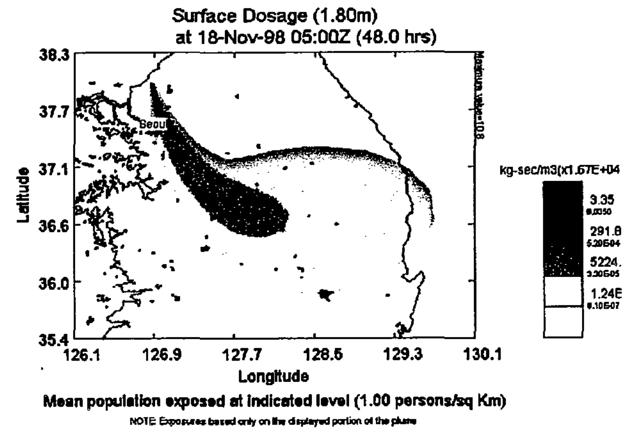
Different scales shown

Wind A

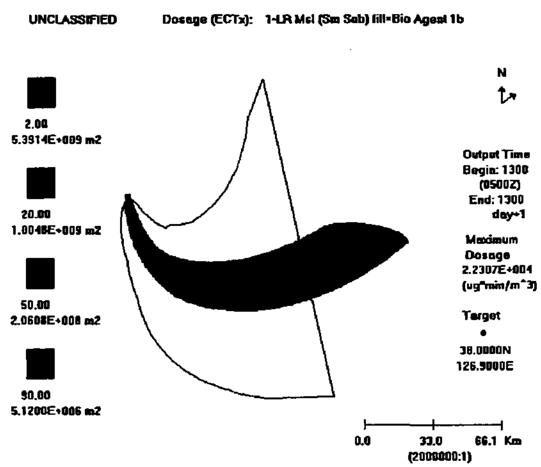
Wind B

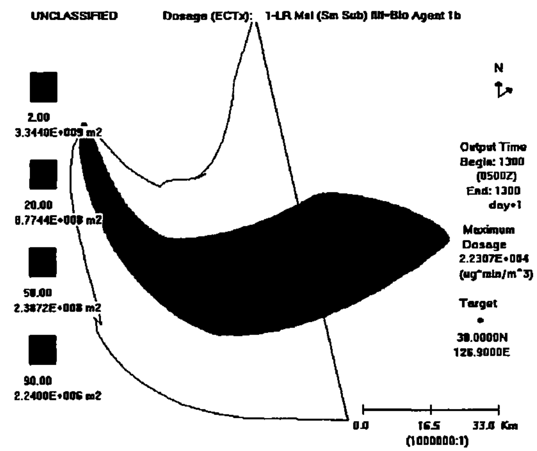
HPAC





VLSTRACK





At E/LCt2 (Wind A/Wind B) Estimated Area (Km^2)	**HPAC [Mean Area]**	**VLSTRACK**
	[21,000/12,900]	5,391/3,344

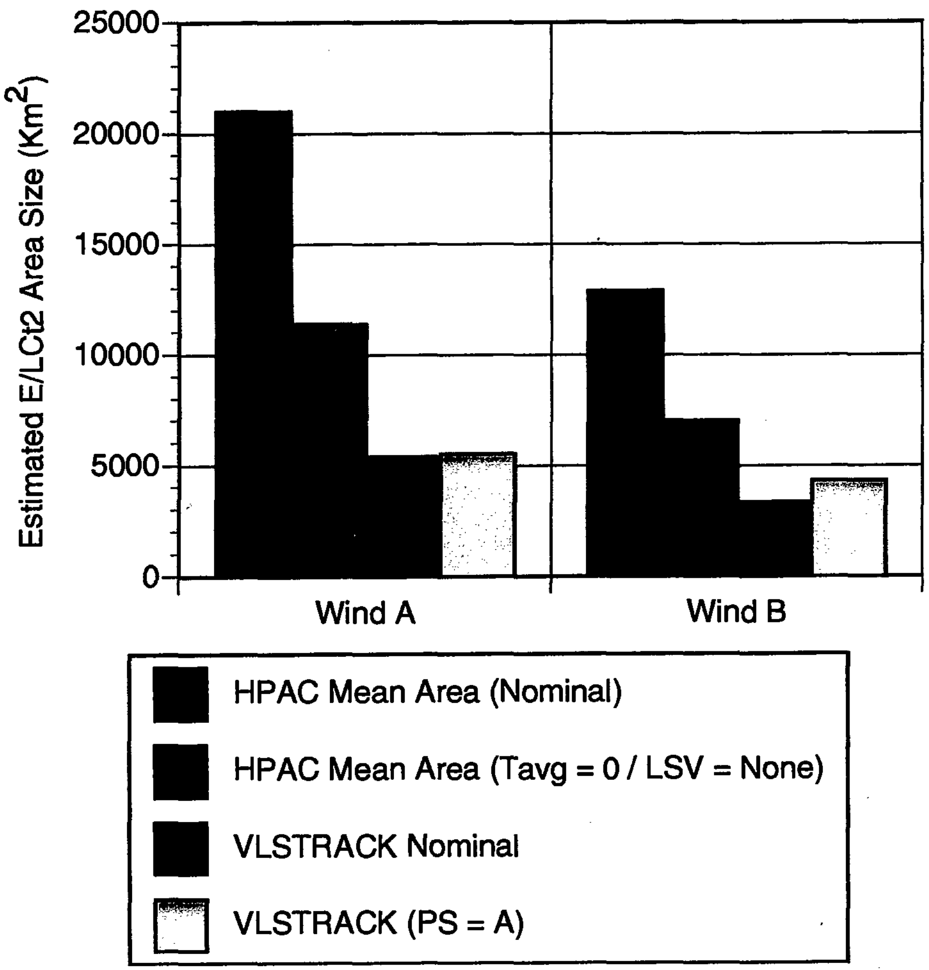
COMPARISON OF HPAC AND VLSTRACK PREDICTIONS FOR BWA RELEASE AND SIMPLE "CURVED" WINDS: DOSAGE (1.8 m)

The bar graphs at right compare four predictions of E/LCt2 for the BWA (dry) release from a ballistic missile with 50 submunitions. On the figure on the left, the blue bars describe the HPAC-predicted LCt2 areas, for curved winds A and B, that result when nominal HPAC uncertainty conditions are assumed (i.e., T_{avg} = default and LSV = operational). The green bars present the HPAC results when one assumes $T_{avg} = 0$ and turns off LSV (i.e., LSV = "none"). The yellow and red bars provide the reported VLSTRACK E/LCt2 area sizes. The yellow bars correspond to the similar settings case (previous slide) and the red bars correspond to the similar settings case with the PS category set to A (very unstable).

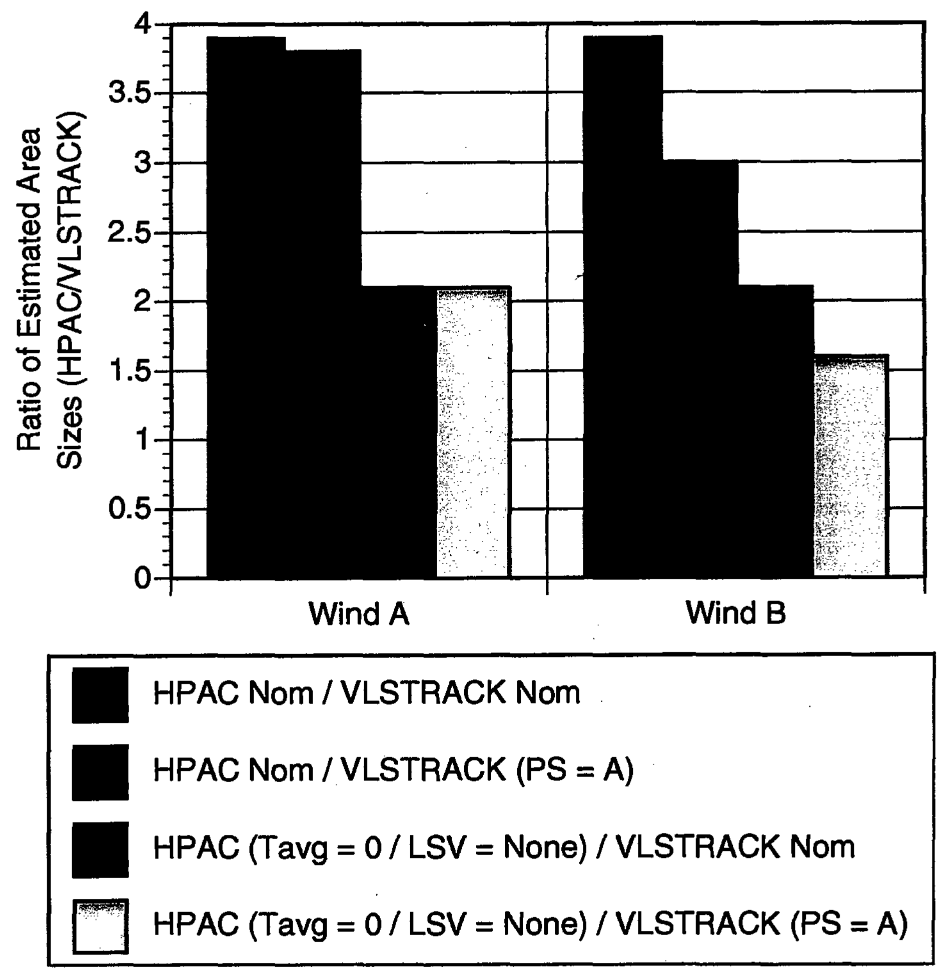
The figure on the right presents the ratios of predicted area sizes at LCt2, HPAC/VLSTRACK, for the various possible comparisons. **The elimination of fundamental HPAC uncertainty features ($T_{avg} = 0$ and LSV = none) resulted in ratios for these curved wind BWA (dry) scenarios that were within a factor of about 2.**

Comparison of HPAC and VLSTRACK Predictions for BWA Release and Simple "Curved" Winds: Dosage (1.8 m)

Predicted Area Sizes



Ratios of Predicted Area Sizes



COMPARISON OF HPAC PREDICTIONS USING HISTORICAL WEATHER AND TERRAIN FEATURES: DOSAGE (1.8 m)

The figures at right show the results of two HPAC calculations. Both calculations involve the same similar settings BWA (dry) ballistic missile release that has been examined on the last few slides. The figure on the left shows the results when the HPAC historical weather feature is used. Rather than using fixed winds or simple time-variable winds, this calculation was done using the historical wind field that was available for this location and time from the HPAC 3.1 CD. Similarly, the figure on the right uses historical weather and incorporates terrain via the HPAC mass consistent wind field model (SWIFT – Stationary Wind Fit and Turbulence).

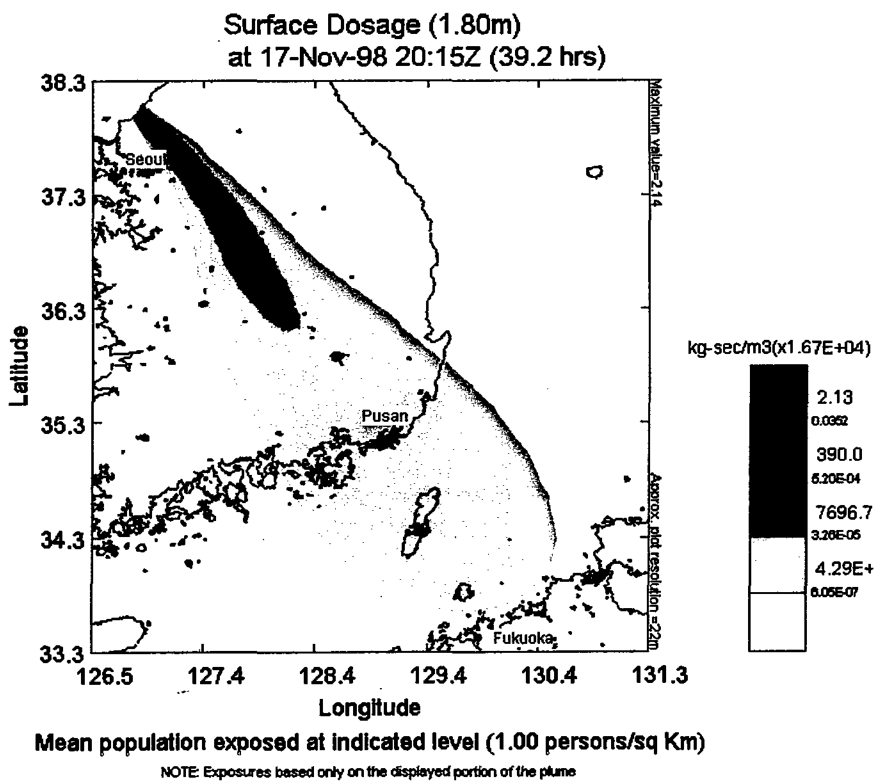
For this particular scenario, the predicted LCt2 areas are similar for the case that includes the HPAC-provided historical weather (based on upper air profiles) and the historical weather plus terrain (SWIFT). However, the operational implications of the two predictions are quite different. In one case, the people of Pusan, South Korea are exposed at the LCt2 level and in the other case they are not.

We made no attempt to validate the accuracy of SWIFT – that is, the figure at right simply demonstrates that the terrain feature of HPAC is easily assessable.

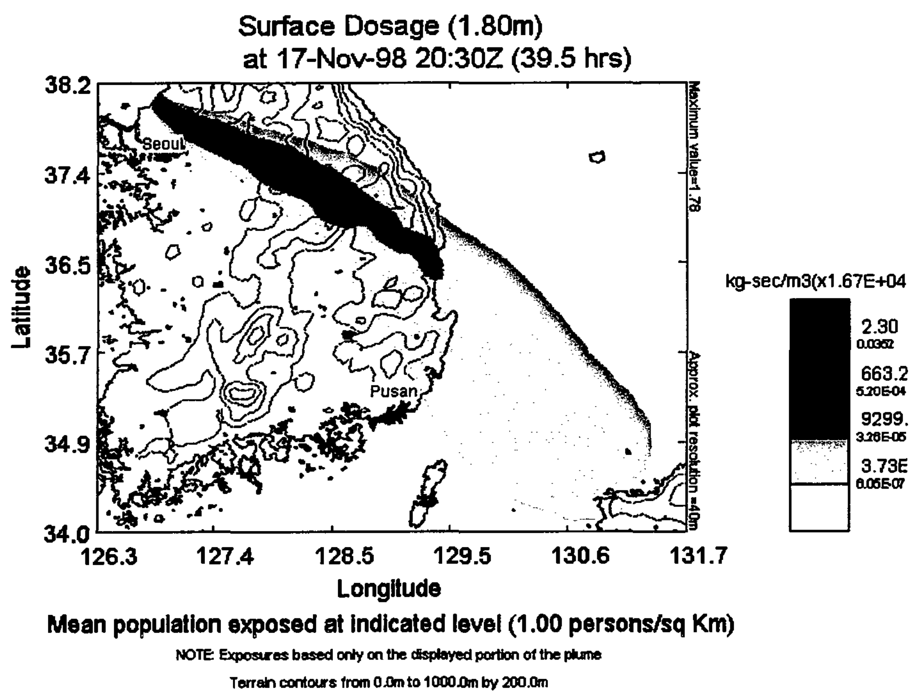
Comparison of HPAC Predictions Using Historical Weather and Terrain Features: Dosage (1.8 m)

BWA (dry) from ballistic missile with 50 submunitions

Historical
Weather



Historical
Weather + Terrain



Different scales shown

At LCt2 (Historical/ + Terrain)	Mean Area	"0.50 Prob (V>E)" Area
Estimated Area (Km^2)	43,200/37,700	38,900/ 38,100

APPENDIX C
INPUT TABLES FOR COMPARATIVE TRIALS

APPENDIX C
INPUT TABLES FOR COMPARATIVE TRIALS

The next 64 pages provide tables that describe the input parameters assumed for each of the comparative trials that we examined. The accompanying chart reports the nomenclature used to identify each table. For example, the sprayer dispersal of GD with a 4 Kph wind and with similar input settings assumed for both VLSTRACK and HPAC is denoted CWPN 1.2.1.

The second column of each table lists the parameters of interest. Columns 4 and 5 provide the values used for VLSTRACK 1.6.3 and HPAC 3.1, respectively.

Each table is divided into two sections. On the right-hand side page, source and location inputs are described. On the left-hand side page, meteorological, environmental, terrain (MET) and output parameters are listed. In general, boldfaced numbers correspond to parameter values that differed between models when the default settings were chosen.

Following this appendix, Appendix D provides an extract of the associated task order for this study and Appendix E provides a list of acronyms.

Appendix C
Input Tables for Comparative Trials

- **Chemical weapons trials = CWPN**
  - Sprayer dispersal of GD
    - » Default Settings: 1.10 (15 Kph), 1.11 (4 Kph), and 1.12 (30 Kph)
    - » Similar Settings: 1.20, 1.21, and 1.22
  - GB from artillery
    - » Default Settings = 2.10 and Similar Settings = 2.11
  - VX and thickened VX from ballistic missile
    - » Default Settings: 3.10 (VX at 300 m), 3.11 (VX at 1,000 m), 3.12 (TVX at 1,000 m), and 3.13 (TVX at 10,000 m)
    - » Similar Settings: 3.20, 3.21, 3.22, and 3.23

- **Biological weapons trials = BWPN**
  - Sprayer
    - » Default Settings: 1.10 (BWA-wet), 1.11 (BWA-dry), 1.20 (BWB-wet), 1.21 (BWB-dry), 1.30 (BWC)
    - » Similar Settings: 1.12, 1.13, 1.22, 1.23, and 1.31
  - Ballistic missile with submunitions
    - » Default Settings: 2.10 (BWA-dry), 2.20 (BWB-dry), 2.30 (BWC)
    - » Similar Settings: 2.11, 2.21, and 2.31

RUN NAME	CWPN1.10	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		**GD**	**GD**
	mass		1,000 Kg	1,000 Kg
	munition		sprayer	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		**6 m**	
	initial size			**15 m**
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			4 s
	rate			250 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed		na	200 m/s
	fall angle		0	0
	dissemination efficiency		100%	100%
	# bins			20
	mass median drop diameter		**500**	**200**
	sigma d		**1.7**	**2**
	droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		9/29/98	9/29/98
	start time		12:00 UTC/ 15:00 Loc	12:00 UTC/ 15:00 Loc

RUN NAME	CWPN1.10	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		*15 kph*	*15 Kph*
	wind type/MET mode		time variable	Fixed
	wind direction		15 deg	15 deg
	wind measurement height		2 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		32 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
	secondary evaporation		rapid approx.	
	MET time bin size		4 hr	na
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default (C)	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN1.11	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		GD	GD
	mass		1,000 Kg	1,000 Kg
	munition		sprayer	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		**6 m**	
	initial size			**15 m**
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			4 s
	rate			250 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed		na	200 m/s
	fall angle		0	0
	dissemination efficiency		100%	100%
	# bins			20
	mass median drop diameter		**500**	**200**
	sigma d		**1.7**	**2**
	droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		9/29/98	9/29/98
	start time		12:00 UTC/ 15:00 Loc	12:00 UTC/ 15:00 Loc

RUN NAME	CWPN1.11	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		*4 kph*	*4 Kph*
	wind type/MET mode		time variable	Fixed
	wind direction		15 deg	15 deg
	wind measurement height		2 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		32 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
	secondary evaporation		rapid approx.	
	MET time bin size		4 hr	na
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default (B)	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN1.12	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		GD	GD
	mass		1,000 Kg	1,000 Kg
	munition		sprayer	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		6 m	
	initial size			15 m
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			4 s
	rate			250 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed		na	200 m/s
	fall angle		0	0
	dissemination efficiency		100%	100%
	# bins			20
	mass median drop diameter		500	200
	sigma d		1.7	2
	droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		9/29/98	9/29/98
	start time		12:00 UTC/ 15:00 Loc	12:00 UTC/ 15:00 Loc

RUN NAME	CWPN1.12	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		*30 kph*	*30 Kph*
	wind type/MET mode		time variable	Fixed
	wind direction		15 deg	15 deg
	wind measurement height		2 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		32 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
	secondary evaporation		rapid approx.	
	MET time bin size		4 hr	na
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default (D)	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN1.20	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		GD	GD
	mass		1,000 Kg	1,000 Kg
	munition		sprayer	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		**15 m**	
	initial size			**15 m**
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			4 s
	rate			250 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed		na	200 m/s
	fall angle		0	0
	dissemination efficiency		100%	100%
	# bins			20
	mass median drop diameter		**200**	**200**
	sigma d		**2**	**2**
	droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		9/29/98	9/29/98
	start time		12:00 UTC/ 15:00 Loc	12:00 UTC/ 15:00 Loc

RUN NAME	CWPN1.20	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		*15 kph*	*15 Kph*
	wind type/MET mode		time variable	Fixed
	wind direction		15 deg	15 deg
	wind measurement height		**10 m**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	air temperature		32 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
	secondary evaporation		rapid approx.	
	MET time bin size		4 hr	na
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default **(C)**	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN1.21	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		GD	GD
	mass		1,000 Kg	1,000 Kg
	munition		sprayer	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		15 m	
	initial size			15 m
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			4 s
	rate			250 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed		na	200 m/s
	fall angle		0	0
	dissemination efficiency		100%	100%
	# bins			20
	mass median drop diameter		200	200
	sigma d		2	2
	droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		9/29/98	9/29/98
	start time		12:00 UTC/ 15:00 Loc	12:00 UTC/ 15:00 Loc

RUN NAME	CWPN1.21	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		*4 kph*	*4 Kph*
	wind type/MET mode		time variable	Fixed
	wind direction		15 deg	15 deg
	wind measurement height		**10 m**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	air temperature		32 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
	secondary evaporation		rapid approx.	
	MET time bin size		4 hr	na
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default (B)	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN1.22	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		GD	GD
	mass		1,000 Kg	1,000 Kg
	munition		sprayer	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		**15 m**	
	initial size			**15 m**
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			4 s
	rate			250 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed		na	200 m/s
	fall angle		0	0
	dissemination efficiency		100%	100%
	# bins			20
	mass median drop diameter		**200**	**200**
	sigma d		**2**	**2**
	droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		9/29/98	9/29/98
	start time		12:00 UTC/ 15:00 Loc	12:00 UTC/ 15:00 Loc

RUN NAME	CWPN1.22	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		***30 kph***	***30 Kph***
	wind type/MET mode		time variable	Fixed
	wind direction		15 deg	15 deg
	wind measurement height		**10 m**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	air temperature		32 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
	secondary evaporation		rapid approx.	
	MET time bin size		4 hr	na
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default **(D)**	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN2.10	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		GB	GB
	mass		4 Kg	2.6 Kg
	munition		152 ARTY	152 Artillery Batt. Fire
	rate of fire		10 rds/min	
	height of release		0 m	2 m
	lateral sigma		3 m	
	vertical sigma		1.3 m	
	initial size			6 m
	detonation coordinates		Gaussian	
	# submunitions		300	75
	spread			250 m
	trajectory angle		180 deg	
	dissemination efficiency		60%	100%
	# bins			20
mass median drop diameter			150	200
	sigma d		1.7	2
geo droplet distribution/size bin dist				Log Normal
	min decay rate			0
	max decay rate			0
Location	LAT		38 N	38 N
	LON		126.9 E	126.9 E
	Date		10/23/98	10/23/98
	start time		23:00 Z/7:00 Loc	23:00 UTC/ 7:00 Loc

RUN NAME	CWPN2.10	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		8 Kph	8 Kph
	wind type/MET mode		time variable	Fixed
	wind meander seed		863005	
	wind direction		295 deg	295
	wind measurement height		2 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	# vertical MET levels		na	
	air temperature		13 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		overcast	overcast
	fractional cloud cover			1
	precipitation			none
	albedo			0.12
	Bowen ratio			1
	terrain			off
	surface type		forest	forest
	surface roughness/canopy hgt			10.00 (canopy)
	surface moisture			normal
	secondary evaporation		rapid approx.	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default (D)	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN2.11	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		GB	GB
	mass		4 Kg	4 Kg
	munition		User Defined	152 Artillery Batt. Fire
	rate of fire		10 rds/min	
	height of release		0 m	0 m
	lateral sigma		3 m	
	vertical sigma		1.3 m	
	initial size			3 m
	detonation coordinates		Gaussian	
	# submunitions		75	75
	spread			250 m
	trajectory angle		180 deg	
	dissemination efficiency		60%	60%
	# bins			20
	mass median drop diameter		200	200
	sigma d		2	2
	geo droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
Location	LAT		38 N	38 N
	LON		126.9 E	126.9 E
	Date		10/23/98	10/23/98
	start time		23:00 Z/7:00 Loc	23:00 UTC/ 7:00 Loc

RUN NAME	CWPN2.11	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		8 Kph	8 Kph
	wind type/MET mode		time variable	Fixed
	wind meander seed		863005	
	wind direction		295 deg	295
	wind measurement height		**10 m**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	# vertical MET levels		na	
	air temperature		13 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		overcast	overcast
	fractional cloud cover			1
	precipitation			none
	albedo			0.12
	Bowen ratio			1
	terrain			off
	surface type		forest	forest
	surface roughness/canopy hgt			10.00 (canopy)
	surface moisture			normal
	secondary evaporation		rapid approx.	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default **(D)**	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN3.10	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		**VX**	**VX**
	mass		500 Kg	500 Kg
	agent mass %		NA	
	munition		Medium Range Missile	Ballistic Missile
	height of release		***300 m***	***300 m***
	lateral sigma		6 m	
	vertical sigma		15 m	
	initial size			15 m
	detonation coordinates		Gaussian	
	# submunitions		1	1
	spread			0
	trajectory angle		180 deg	
	puff form duration			0.30 s
	rate			1666.67 Kg/s
	heading			0
	length		**200 m**	**300 m**
	mass center speed /speed		1000 m/s	1000 m/s
	fall angle		**45 deg**	**70 deg**
	dissemination efficiency		**60%**	**100%**
	# bins			20
	mass median drop diameter		**100**	**500**
	sigma d		1.7	1.7
	geo droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
	bio decay rate		na	
Location	LAT		39 N	39 N
	LON		78 W	78 W
	Altitude			not used
	Date		10/30/98	10/30/98
	start time		**18:00 UTC**/12:00 Loc	**17:00** UTC/12:00 Loc

RUN NAME	CWPN3.10	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		13 Kph	13 Kph
	wind type/MET mode		time variable	Fixed
	wind direction		203 deg	203 deg
	wind measurement height		**2 m (default)**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	# vertical MET levels		na	
	air temperature		12 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			none
	cloud cover/precipitation		partly cloudy	broken clouds
	fractional cloud cover			0.5
	precipitation			none
	albedo			0.2
	Bowen ratio			0.9
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt			0.25 (canopy)
	surface moisture			normal
	secondary evaporation		rapid approx.	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default **(C)**	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN3.11	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		VX	VX
	mass		500 Kg	500 Kg
	agent mass %		NA	
	munition		Medium Range Missile	Ballistic Missile
	height of release		*1,000 m*	*1,000 m*
	lateral sigma		6 m	
	vertical sigma		15 m	
	initial size			15 m
	detonation coordinates		Gaussian	
	# submunitions		1	1
	spread			0
	trajectory angle		180 deg	
	puff form duration			0.30 s
	rate			1666.67 Kg/s
	heading			0
	length		**200 m**	**300 m**
	mass center speed /speed		1000 m/s	1000 m/s
	fall angle		**45 deg**	**70 deg**
	dissemination efficiency		**60%**	**100%**
	# bins			20
	mass median drop diameter		**100**	**500**
	sigma d		1.7	1.7
	geo droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
	bio decay rate		na	
Location	LAT		39 N	39 N
	LON		78 W	78 W
	Altitude			not used
	Date		10/30/98	10/30/98
	start time		**18:00 UTC**/12:00 Loc	**17:00** UTC/12:00 Loc

RUN NAME	CWPN3.11	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		13 Kph	13 Kph
	wind type/MET mode		time variable	Fixed
	wind direction		203 deg	203 deg
	wind measurement height		**2 m (default)**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	# vertical MET levels		na	
	air temperature		12 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			none
	cloud cover/precipitation		partly cloudy	broken clouds
	fractional cloud cover			0.5
	precipitation			none
	albedo			0.2
	Bowen ratio			0.9
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt			0.25 (canopy)
	surface moisture			normal
	secondary evaporation		rapid approx.	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default (C)	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN3.12	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		TVX	TVX
	mass		500 Kg	500 Kg
	agent mass %		NA	
	munition		Medium Range Missile	Ballistic Missile
	height of release		*1,000 m*	*1,000 m*
	lateral sigma		6 m	
	vertical sigma		15 m	
	initial size			15 m
	detonation coordinates		Gaussian	
	# submunitions		1	1
	spread			0
	trajectory angle		180 deg	
	puff form duration			0.30 s
	rate			1666.67 Kg/s
	heading			0
	length		**200 m**	**300 m**
	mass center speed /speed		1000 m/s	1000 m/s
	fall angle		**45 deg**	**70 deg**
	dissemination efficiency		**60%**	**100%**
	# bins			20
	mass median drop diameter		**500**	**2,500**
	sigma d		1.7	1.7
	geo droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
	bio decay rate		na	
Location	LAT		39 N	39 N
	LON		78 W	78 W
	Altitude			not used
	Date		10/30/98	10/30/98
	start time		**18:00 UTC**/12:00 Loc	**17:00** UTC/12:00 Loc

RUN NAME	CWPN3.12	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		13 Kph	13 Kph
	wind type/MET mode		time variable	Fixed
	wind direction		203 deg	203 deg
	wind measurement height		**2 m (default)**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	# vertical MET levels		na	
	air temperature		12 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			none
	cloud cover/precipitation		partly cloudy	broken clouds
	fractional cloud cover			0.5
	precipitation			none
	albedo			0.2
	Bowen ratio			0.9
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt			0.25 (canopy)
	surface moisture			normal
	secondary evaporation		rapid approx.	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default **(C)**	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN3.13	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		TVX	TVX
	mass		500 Kg	500 Kg
	agent mass %		NA	
	munition		Medium Range Missile	Ballistic Missile
	height of release		*10,000 m*	*10,000 m*
	lateral sigma		6 m	
	vertical sigma		15 m	
	initial size			15 m
	detonation coordinates		Gaussian	
	# submunitions		1	1
	spread			0
	trajectory angle		180 deg	
	puff form duration			0.30 s
	rate			1666.67 Kg/s
	heading			0
	length		**200 m**	**300 m**
	mass center speed /speed		1000 m/s	1000 m/s
	fall angle		**45 deg**	**70 deg**
	dissemination efficiency		**60%**	**100%**
	# bins			20
	mass median drop diameter		**500**	**2,500**
	sigma d		1.7	1.7
	geo droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
	bio decay rate		na	
Location	LAT		39 N	39 N
	LON		78 W	78 W
	Altitude			not used
	Date		10/30/98	10/30/98
	start time		**18:00 UTC**/12:00 Loc	**17:00** UTC/12:00 Loc

RUN NAME	CWPN3.13	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		13 Kph	13 Kph
	wind type/MET mode		time variable	Fixed
	wind direction		203 deg	203 deg
	wind measurement height		**2 m (default)**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	# vertical MET levels		na	
	air temperature		12 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			none
	cloud cover/precipitation		partly cloudy	broken clouds
	fractional cloud cover			0.5
	precipitation			none
	albedo			0.2
	Bowen ratio			0.9
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt			0.25 (canopy)
	surface moisture			normal
	secondary evaporation		rapid approx.	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default **(C)**	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			***12,000 m***
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN3.20	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		VX	VX
	mass		500 Kg	500 Kg
	agent mass %		NA	
	munition		Medium Range Missile	Ballistic Missile
	height of release		*300 m*	*300 m*
	lateral sigma		6 m	
	vertical sigma		15 m	
	initial size			15 m
	detonation coordinates		Gaussian	
	# submunitions		1	1
	spread			0
	trajectory angle		180 deg	
	puff form duration			0.30 s
	rate			1666.67 Kg/s
	heading			0
	length		200 m	200 m
	mass center speed /speed		1000 m/s	1000 m/s
	fall angle		45 deg	45 deg
	dissemination effeciency		60%	60%
	# bins			20
	mass median drop diameter		100	100
	sigma d		1.7	1.7
	geo droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
	bio decay rate		na	
Location	LAT		39 N	39 N
	LON		78 W	78 W
	Altitude			not used
	Date		10/30/98	10/30/98
	start time		17:00 UTC/11:00 Loc	17:00 UTC/12:00 Loc

RUN NAME	CWPN3.20	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		13 Kph	13 Kph
	wind type/MET mode		time variable	Fixed
	wind direction		203 deg	203 deg
	wind measurement height		10 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	# vertical MET levels		na	
	air temperature		12 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			none
	cloud cover/precipitation		partly cloudy	broken clouds
	fractional cloud cover			0.5
	precipitation			none
	albedo			0.2
	Bowen ratio			0.9
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt			0.25 (canopy)
	surface moisture			normal
	secondary evaporation		rapid approx.	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default (C)	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN3.21	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		**VX**	**VX**
	mass		500 Kg	500 Kg
	agent mass %		NA	
	munition		Medium Range Missile	Ballistic Missile
	height of release		***1,000 m***	***1,000 m***
	lateral sigma		6 m	
	vertical sigma		15 m	
	initial size			15 m
	detonation coordinates		Gaussian	
	# submunitions		1	1
	spread			0
	trajectory angle		180 deg	
	puff form duration			0.30 s
	rate			1666.67 Kg/s
	heading			0
	length		**200 m**	**200 m**
	mass center speed /speed		1000 m/s	1000 m/s
	fall angle		**45 deg**	**45 deg**
	dissemination effeciency		**60%**	**60%**
	# bins			20
	mass median drop diameter		**100**	**100**
	sigma d		1.7	1.7
	geo droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
	bio decay rate		na	
Location	LAT		39 N	39 N
	LON		78 W	78 W
	Altitude			not used
	Date		10/30/98	10/30/98
	start time		**17:00 UTC**/11:00 Loc	**17:00** UTC/12:00 Loc

RUN NAME	CWPN3.21	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		13 Kph	13 Kph
	wind type/MET mode		time variable	Fixed
	wind direction		203 deg	203 deg
	wind measurement height		10 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	# vertical MET levels		na	
	air temperature		12 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			none
	cloud cover/precipitation		partly cloudy	broken clouds
	fractional cloud cover			0.5
	precipitation			none
	albedo			0.2
	Bowen ratio			0.9
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt			0.25 (canopy)
	surface moisture			normal
	secondary evaporation		rapid approx.	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default (C)	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN3.22	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		TVX	TVX
	mass		500 Kg	500 Kg
	agent mass %		NA	
	munition		Medium Range Missile	Ballistic Missile
	height of release		*1,000 m*	*1,000 m*
	lateral sigma		6 m	
	vertical sigma		15 m	
	initial size			15 m
	detonation coordinates		Gaussian	
	# submunitions		1	1
	spread			0
	trajectory angle		180 deg	
	puff form duration			0.30 s
	rate			1666.67 Kg/s
	heading			0
	length		**200 m**	**200 m**
	mass center speed /speed		1000 m/s	1000 m/s
	fall angle		**45 deg**	**45 deg**
	dissemination efficiency		**60%**	**60%**
	# bins			15
	mass median drop diameter		**500**	**500**
	sigma d		1.7	1.7
	geo droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
	bio decay rate		na	
Location	LAT		39 N	39 N
	LON		78 W	78 W
	Altitude			not used
	Date		10/30/98	10/30/98
	start time		**17:00 UTC**/11:00 Loc	**17:00** UTC/12:00 Loc

RUN NAME	CWPN3.22	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		13 Kph	13 Kph
	wind type/MET mode		time variable	Fixed
	wind direction		203 deg	203 deg
	wind measurement height		**10 m (default)**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	# vertical MET levels		na	
	air temperature		12 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			none
	cloud cover/precipitation		partly cloudy	broken clouds
	fractional cloud cover			0.5
	precipitation			none
	albedo			0.2
	Bowen ratio			0.9
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt			0.25 (canopy)
	surface moisture			normal
	secondary evaporation		rapid approx.	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default **(C)**	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			5,000 m
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	CWPN3.23	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		TVX	TVX
	mass		500 Kg	500 Kg
	agent mass %		NA	
	munition		Medium Range Missile	Ballistic Missile
	height of release		*10,000 m*	*10,000 m*
	lateral sigma		6 m	
	vertical sigma		15 m	
	initial size			15 m
	detonation coordinates		Gaussian	
	# submunitions		1	1
	spread			0
	trajectory angle		180 deg	
	puff form duration			0.30 s
	rate			1666.67 Kg/s
	heading			0
	length		**200 m**	**200 m**
	mass center speed /speed		1000 m/s	1000 m/s
	fall angle		**45 deg**	**45 deg**
	dissemination efficiency		**60%**	**60%**
	# bins			15
	mass median drop diameter		**500**	**500**
	sigma d		1.7	1.7
	geo droplet distribution/size bin dist			Log Normal
	min decay rate			0
	max decay rate			0
	bio decay rate		na	
Location	LAT		39 N	39 N
	LON		78 W	78 W
	Altitude			not used
	Date		10/30/98	10/30/98
	start time		**17:00 UTC**/11:00 Loc	**17:00** UTC/12:00 Loc

RUN NAME	CWPN3.23	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		13 Kph	13 Kph
	wind type/MET mode		time variable	Fixed
	wind direction		203 deg	203 deg
	wind measurement height		**10 m (default)**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	# vertical MET levels		na	
	air temperature		12 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			none
	cloud cover/precipitation		partly cloudy	broken clouds
	fractional cloud cover			0.5
	precipitation			none
	albedo			0.2
	Bowen ratio			0.9
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt			0.25 (canopy)
	surface moisture			normal
	secondary evaporation		rapid approx.	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default **(C)**	
OUTPUTS	dose height		1.8 m	1.8 m
	horiz domain resolution			default
	vertical domain			***12,000 m***
	vert domain resolution			default
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN1.10	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		**BWA (wet)**	**BWA**
	mass		1,000 Kg	1,000 Kg
	munition		User Defined	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		**6 m**	
	vertical sigma			
	initial size			**10 m**
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			8 s
	rate			75 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed			100 m/s
	fall angle			0
	dissemination efficiency		**10%**	**60%**
	# bins			1
	mass median drop diameter		**3**	**5**
	sigma d		**1.5**	**1.01**
	droplet distribution/size bin dist			Log Normal
	min decay rate		**0.1**	**0.1002**
	max decay rate		**1**	**1.002**
	bio decay rate		normal	
	viable fraction / purity		**2%**	**100%**
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		11/6/98	11/6/98
	start time		23:00 UTC/ 02:00 Loc	23:00 UTC/ 02:00 Loc

RUN NAME	BWPN1.10	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		15 Kph	15 Kph
	wind direction		15 deg	15 deg
	wind measurement height		2 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		18 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN1.11	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWA (dry)	BWA
	mass		1,000 Kg	1,000 Kg
	munition		User Defined	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		6 m	
	vertical sigma			
	initial size			10 m
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			8 s
	rate			75 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed			100 m/s
	fall angle			0
	dissemination efficiency		60%	60%
	# bins			1
	mass median drop diameter		3	5
	sigma d		1.5	1.01
	droplet distribution/size bin dist			Log Normal
	min decay rate		0.2	0.1002
	max decay rate		2	1.002
	bio decay rate		normal	
	viable fraction / purity		90%	100%
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		11/6/98	11/6/98
	start time		23:00 UTC/ 02:00 Loc	23:00 UTC/ 02:00 Loc

RUN NAME	BWPN1.11	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		15 Kph	15 Kph
	wind direction		15 deg	15 deg
	wind measurement height		**2 m (default)**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	air temperature		18 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN1.20	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWB (wet)	BWB
	mass		1,000 Kg	1,000 Kg
	munition		User Defined	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		6 m	
	vertical sigma			
	initial size			15 m
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			8 s
	rate			75 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed			100 m/s
	fall angle			0
	dissemination efficiency		10%	60%
	# bins			1
	mass median drop diameter		5	5
	sigma d		1.5	1.01
	droplet distribution/size bin dist			Log Normal
	min decay rate		0.4	0.1002
	max decay rate		3.9	1.002
	bio decay rate		normal	
	viable fraction / purity		10%	100%
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		11/6/98	11/6/98
	start time		23:00 UTC/ 02:00 Loc	23:00 UTC/ 02:00 Loc

RUN NAME	BWPN1.20	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		15 Kph	15 Kph
	wind direction		15 deg	15 deg
	wind measurement height		2 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		18 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN1.21	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWB (dry)	BWB
	mass		1,000 Kg	1,000 Kg
	munition		User Defined	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		6 m	
	vertical sigma			
	initial size			15 m
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			8 s
	rate			75 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
mass center speed /speed				100 m/s
	fall angle			0
	dissemination efficiency		60%	60%
	# bins			1
mass median drop diameter			5	5
	sigma d		1.5	1.01
droplet distribution/size bin dist				Log Normal
	min decay rate		0.8	0.1002
	max decay rate		7.8	1.002
	bio decay rate		normal	
	viable fraction / purity		50%	100%
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		11/6/98	11/6/98
	start time		23:00 UTC/ 02:00 Loc	23:00 UTC/ 02:00 Loc

RUN NAME	BWPN1.21	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		15 Kph	15 Kph
	wind direction		15 deg	15 deg
wind measurement height			2 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		18 C	
	boundary layer/type			operational
lumped boundary layer option				off
inversion hgt (night/day)				na
sensible heat flux (night/day)				na
	large scale variability			operational
cloud cover/precipitation			clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
surface roughness/canopy hgt				0.01
	surface moisture			dry
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
Pasquill stability category			program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN1.30	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		**BWC**	**BWC**
	mass		1,000 Kg	1,000 Kg
	munition		User Defined	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		**6 m**	
	vertical sigma			
	initial size			**25 m**
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			8 s
	rate			75 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed			100 m/s
	fall angle			0
	dissemination efficiency		60%	60%
	# bins			1
	mass median drop diameter		5	5
	sigma d		**1.5**	**1.01**
	droplet distribution/size bin dist			Log Normal
	min decay rate		**0.1**	**0**
	max decay rate		**1**	**0**
	bio decay rate		normal	
	viable fraction / purity		**70%**	**100%**
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		11/6/98	11/6/98
	start time		23:00 UTC/ 02:00 Loc	23:00 UTC/ 02:00 Loc

RUN NAME	BWPN1.30	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		15 Kph	15 Kph
	wind direction		15 deg	15 deg
	wind measurement height		2 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		18 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN1.12	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWA (wet)	BWA
	mass		1,000 Kg	20 Kg
	munition		User Defined	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		6 m	
	vertical sigma			
	initial size			6 m
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			8 s
	rate			75 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed			100 m/s
	fall angle			0
	dissemination efficiency		10%	10%
	# bins			1
	mass median drop diameter		3	3
	sigma d		1.5	1.5
	droplet distribution/size bin dist			Log Normal
	min decay rate		0.1	0.1002
	max decay rate		1	1.002
	bio decay rate		normal	
	viable fraction / purity		2%	simulated with mass
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		11/6/98	11/6/98
	start time		23:00 UTC/ 02:00 Loc	23:00 UTC/ 02:00 Loc

RUN NAME	BWPN1.12	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		15 Kph	15 Kph
	wind direction		15 deg	15 deg
wind measurement height			10 m	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		18 C	
	boundary layer/type			operational
lumped boundary layer option				off
inversion hgt (night/day)				na
sensible heat flux (night/day)				na
	large scale variability			operational
cloud cover/precipitation			clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
surface roughness/canopy hgt				0.01
	surface moisture			dry
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
Pasquill stability category			program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN1.13	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWA (dry)	BWA
	mass		1,000 Kg	900 Kg
	munition		User Defined	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		6 m	
	vertical sigma			
	initial size			6 m
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			8 s
	rate			75 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed			100 m/s
	fall angle			0
	dissemination efficiency		60%	60%
	# bins			1
	mass median drop diameter		3	3
	sigma d		1.5	1.5
	droplet distribution/size bin dist			Log Normal
	min decay rate		0.2	0.2
	max decay rate		2	2
	bio decay rate		normal	
	viable fraction / purity		90%	simulated with mass
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		11/6/98	11/6/98
	start time		23:00 UTC/ 02:00 Loc	23:00 UTC/ 02:00 Loc

RUN NAME	BWPN1.13	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		15 Kph	15 Kph
	wind direction		15 deg	15 deg
	wind measurement height		10 m	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		18 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN1.22	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		**BWB (wet)**	**BWB**
	mass		**1,000 Kg**	**100 Kg**
	munition		User Defined	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		**6 m**	
	vertical sigma			
	initial size			**6 m**
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			8 s
	rate			75 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed			100 m/s
	fall angle			0
	dissemination efficiency		**10%**	**10%**
	# bins			1
	mass median drop diameter		5	5
	sigma d		**1.5**	**1.5**
	droplet distribution/size bin dist			Log Normal
	min decay rate		**0.4**	**0.4**
	max decay rate		**3.9**	**3.9**
	bio decay rate		normal	
	viable fraction / purity		**10%**	**simulated with mass**
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		11/6/98	11/6/98
	start time		23:00 UTC/ 02:00 Loc	23:00 UTC/ 02:00 Loc

RUN NAME	BWPN1.22	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		15 Kph	15 Kph
	wind direction		15 deg	15 deg
	wind measurement height		10 m	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		18 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN1.23 Parameter	Model	VLSTRACK 1.6.3	HPAC 3.1
Source	agent		BWB (dry)	BWB
	mass		1,000 Kg	500 Kg
	munition		User Defined	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		6 m	
	vertical sigma			
	initial size			6 m
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			8 s
	rate			75 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed			100 m/s
	fall angle			0
	dissemination efficiency		60%	60%
	# bins			1
	mass median drop diameter		5	5
	sigma d		1.5	1.5
	droplet distribution/size bin dist			Log Normal
	min decay rate		0.8	0.8
	max decay rate		7.8	7.8
	bio decay rate		normal	
	viable fraction / purity		50%	simulated with mass
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		11/6/98	11/6/98
	start time		23:00 UTC/ 02:00 Loc	23:00 UTC/ 02:00 Loc

RUN NAME	BWPN1.23	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	**wind speed**		15 Kph	15 Kph
	wind direction		15 deg	15 deg
	wind measurement height		**10 m**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	air temperature		18 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
stable atmosphere	**turbulence**			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	**turbulence**			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	**dose height**		1.8 m	1.8 m
	vertical domain			5,000 m
Other	**puff split grid level**			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN1.31	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWC	BWC
	mass		1,000 Kg	700 Kg
	munition		User Defined	Aerial Sprayer
	height of release		100 m	100 m
	lateral sigma		6 m	
	vertical sigma			
	initial size			6 m
	detonation coordinates		Gaussian	
	trajectory angle		285 deg	
	puff form duration			8 s
	rate			75 Kg/s
	heading			285 deg
	line length		800 m	
	length			800 m
	mass center speed /speed			100 m/s
	fall angle			0
	dissemination efficiency		60%	60%
	# bins			1
	mass median drop diameter		5	5
	sigma d		1.5	1.5
	droplet distribution/size bin dist			Log Normal
	min decay rate		0.1	0.1
	max decay rate		1	1
	bio decay rate		normal	
	viable fraction / purity		70%	simulated with mass
Location	LAT		30 N	30 N
	LON		45 E	45 E
	Date		11/6/98	11/6/98
	start time		23:00 UTC/ 02:00 Loc	23:00 UTC/ 02:00 Loc

RUN NAME	BWPN1.31	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		15 Kph	15 Kph
	wind direction		15 deg	15 deg
	wind measurement height		10 m	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		18 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		clear	clear
	fractional cloud cover			0
	precipitation			none
	albedo			0.3
	Bowen ratio			6
	terrain			off
	surface type		barren	desert
	surface roughness/canopy hgt			0.01
	surface moisture			dry
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN2.10	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWA (dry)	BWA
	mass		3 Kg per sub	1.56 Kg per sub
	munition		LR Msl (sm sub)	Ballistic Missile
	height of release		0 m	2 m
	lateral sigma		4 m	
	vertical sigma		1.4 m	
	initial size			5 m
	detonation coordinates		Gaussian	
	# submunitions		50	50
	spread			8000 m
	trajectory angle		0	0
	dissemination efficiency		3%	5%
	Viable agent / purity		90%	100%
	# bins			1
	mass median drop diameter		3	5
	sigma d		1.5	1.01
	geo droplet distribution/size bin dist			Log Normal
	min decay rate		0.2	0.1002
	max decay rate		2	1.002
	bio decay rate		normal	
Location	LAT		38 N	38 N
	LON		126.9 E	126.9 E
	Date		11/16/98	11/16/98
	start time		5:00 Z / 13:00 Loc	5:00 Z / 13:00 Loc

RUN NAME	BWPN2.10	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		6 Kph	6 Kph
	wind type/MET mode		fixed wind	fixed wind
	wind direction		350 deg	350 deg
	wind measurement height		2 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		5 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		overcast	overcast
	fractional cloud cover			1
	precipitation			none
	albedo			0.2
	Bowen ratio			0.4
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt		na	0.25
	surface moisture			wet
	secondary evaporation		default	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN2.20	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWB (dry)	BWB
	mass		3 Kg per sub	1.56 Kg per sub
	munition		LR Msl (sm sub)	Ballistic Missile
	height of release		0 m	2 m
	lateral sigma		4 m	
	vertical sigma		1.4 m	
	initial size			5 m
	detonation coordinates		Gaussian	
	# submunitions		50	50
	spread			8000 m
	trajectory angle		0	0
	dissemination efficiency		3%	5%
	Viable agent / purity		50%	100%
	# bins			1
mass median drop diameter			5	5
	sigma d		1.5	1.01
geo droplet distribution/size bin dist				Log Normal
	min decay rate		0.8	0.1002
	max decay rate		7.8	1.002
	bio decay rate		normal	
Location	LAT		38 N	38 N
	LON		126.9 E	126.9 E
	Date		11/16/98	11/16/98
	start time		5:00 Z / 13:00 Loc	5:00 Z / 13:00 Loc

RUN NAME	BWPN2.20	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		6 Kph	6 Kph
	wind type/MET mode		fixed wind	fixed wind
	wind direction		350 deg	350 deg
	wind measurement height		2 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		5 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		overcast	overcast
	fractional cloud cover			1
	precipitation			none
	albedo			0.2
	Bowen ratio			0.4
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt		na	0.25
	surface moisture			wet
	secondary evaporation		default	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN2.30	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWC	BWC
	mass		3 Kg per sub	1.56 Kg per sub
	munition		LR Msl (sm sub)	Ballistic Missile
	height of release		0 m	2 m
	lateral sigma		4 m	
	vertical sigma		1.4 m	
	initial size			5 m
	detonation coordinates		Gaussian	
	# submunitions		50	50
	spread			8000 m
	trajectory angle		0	0
	dissemination efficiency		3%	5%
	Viable agent / purity		70%	100%
	# bins			1
	mass median drop diameter		5	5
	sigma d		1.5	1.01
	geo droplet distribution/size bin dist			Log Normal
	min decay rate		0.1	0
	max decay rate		1	0
	bio decay rate		normal	
Location	LAT		38 N	38 N
	LON		126.9 E	126.9 E
	Date		11/16/98	11/16/98
	start time		5:00 Z / 13:00 Loc	5:00 Z / 13:00 Loc

RUN NAME	BWPN2.30	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		6 Kph	6 Kph
	wind type/MET mode		fixed wind	fixed wind
	wind direction		350 deg	350 deg
	wind measurement height		2 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		5 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		overcast	overcast
	fractional cloud cover			1
	precipitation			none
	albedo			0.2
	Bowen ratio			0.4
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt		na	0.25
	surface moisture			wet
	secondary evaporation		default	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN2.11	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWA (dry)	BWA
	mass		3 Kg per sub	2.7 Kg per sub
	munition		LR Msl (sm sub)	Ballistic Missile
	height of release		0 m	0 m
	lateral sigma		4 m	
	vertical sigma		1.4 m	
	initial size			4 m
	detonation coordinates		Gaussian	
	# submunitions		50	50
	spread			500 m
	trajectory angle		0	0
	dissemination efficiency		3%	3%
	Viable agent / purity		90%	simulated with mass
	# bins			1
	mass median drop diameter		3	3
	sigma d		1.5	1.5
	geo droplet distribution/size bin dist			Log Normal
	min decay rate		0.2	0.2
	max decay rate		2	2
	bio decay rate		normal	
Location	LAT		38 N	38 N
	LON		126.9 E	126.9 E
	Date		11/16/98	11/16/98
	start time		5:00 Z / 13:00 Loc	5:00 Z / 13:00 Loc

RUN NAME	BWPN2.11	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		6 Kph	6 Kph
	wind type/MET mode		fixed wind	fixed wind
	wind direction		350 deg	350 deg
	wind measurement height		10 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		5 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		overcast	overcast
	fractional cloud cover			1
	precipitation			none
	albedo			0.2
	Bowen ratio			0.4
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt		na	0.25
	surface moisture			wet
	secondary evaporation		default	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN2.21	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWB (dry)	BWB
	mass		3 Kg per sub	1.5 Kg per sub
	munition		LR Msl (sm sub)	Ballistic Missile
	height of release		0 m	0 m
	lateral sigma		4 m	
	vertical sigma		1.4 m	
	initial size			4 m
	detonation coordinates		Gaussian	
	# submunitions		50	50
	spread			500 m
	trajectory angle		0	0
	dissemination efficiency		3%	3%
	Viable agent / purity		50%	simulated with mass
	# bins			1
	mass median drop diameter		5	5
	sigma d		1.5	1.5
	geo droplet distribution/size bin dist			Log Normal
	min decay rate		0.8	0.8
	max decay rate		7.8	7.8
	bio decay rate		normal	
Location	LAT		38 N	38 N
	LON		126.9 E	126.9 E
	Date		11/16/98	11/16/98
	start time		5:00 Z / 13:00 Loc	5:00 Z / 13:00 Loc

RUN NAME	BWPN2.21	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		6 Kph	6 Kph
	wind type/MET mode		fixed wind	fixed wind
	wind direction		350 deg	350 deg
	wind measurement height		10 m (default)	10 m (default)
	wind sensitivity		(+/-) 15 deg	
	air temperature		5 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		overcast	overcast
	fractional cloud cover			1
	precipitation			none
	albedo			0.2
	Bowen ratio			0.4
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt		na	0.25
	surface moisture			wet
	secondary evaporation		default	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

RUN NAME	BWPN2.31	Model	VLSTRACK 1.6.3	HPAC 3.1
	Parameter			
Source	agent		BWC	BWC
	mass		3 Kg per sub	2.1 Kg per sub
	munition		LR Msl (sm sub)	Ballistic Missile
	height of release		0 m	0 m
	lateral sigma		4 m	
	vertical sigma		1.4 m	
	initial size			4 m
	detonation coordinates		Gaussian	
	# submunitions		50	50
	spread			500 m
	trajectory angle		0	0
	dissemination efficiency		3%	3%
	Viable agent / purity		70%	simulated with mass
	# bins			1
	mass median drop diameter		5	5
	sigma d		1.5	1.5
	geo droplet distribution/size bin dist			Log Normal
	min decay rate		0.1	0.1
	max decay rate		1	1
	bio decay rate		normal	
Location	LAT		38 N	38 N
	LON		126.9 E	126.9 E
	Date		11/16/98	11/16/98
	start time		5:00 Z / 13:00 Loc	5:00 Z / 13:00 Loc

RUN NAME	BWPN2.31	Model	VLSTRACK 1.6.3	HPAC 3.1
MET	wind speed		6 Kph	6 Kph
	wind type/MET mode		fixed wind	fixed wind
	wind direction		350 deg	350 deg
	wind measurement height		**10 m (default)**	**10 m (default)**
	wind sensitivity		(+/-) 15 deg	
	air temperature		5 C	
	boundary layer/type			operational
	lumped boundary layer option			off
	inversion hgt (night/day)			na
	sensible heat flux (night/day)			na
	large scale variability			operational
	cloud cover/precipitation		overcast	overcast
	fractional cloud cover			1
	precipitation			none
	albedo			0.2
	Bowen ratio			0.4
	terrain			off
	surface type		grass	grassland
	surface roughness/canopy hgt		na	0.25
	surface moisture			wet
	secondary evaporation		default	
stable atmosphere	turbulence			0.01 m2/s2
	scale			10 m
	dissipation			0.0004 m2/s3
calm conditions	turbulence			0.250 m2/s2
	scale			1000 m
	min puff mass			1.00E-20
	conditional averaging			default
	Pasquill stability category		program default	
OUTPUTS	dose height		1.8 m	1.8 m
	vertical domain			5,000 m
Other	puff split grid level			2
	surface resolution			default
	puff grid resolution			0.00 m
	boundary layer points			11

APPENDIX D
TASK ORDER EXTRACT

TASK ORDER (EXTRACT)

TITLE: NBC Hazard Prediction Model Capability Analysis

This task order is for work to be performed by the Institute for Defense Analyses (IDA) under contract DASW01-94-C-0054/DASW01-97-C-0056.

BACKGROUND:

U.S. forces must be able to survive, fight, and win in Nuclear, Biological, and Chemical (NBC) warfare environments. The DoD has sponsored the development, testing, and use of sophisticated and complex computational models to describe environmental contamination resulting from NBC weapons and Counterproliferation activities and accidental or deliberate releases of toxic industrial materials (TIM). In November 1996, acting under combined Congressional mandates, the ATSD (NCB/CBM) and the DUSA(OR) jointly designated three models as "DoD Interim Standard NBC Hazard Prediction Models: (1) VLSTRACK for hazards from CB weapon attacks (i.e. counterproliferation passive defense applications), (2) HPAC for NBC hazards from destruction of NBC facilities (i.e. counterproliferation counter force applications), and (3) D2PCw for industrial chemical hazards from accidents or incidents." Because of continued technology developments, review of these interim designations is required with respect to current quantitative data for model validation. Collaboration within the NBC hazard modeling community in an independently facilitated technical review of model capabilities is required for DATSD (CP/CBD) to establish informed guidance for model applicability.

OBJECTIVES:

The objectives of this study are as follows: (1) Determine whether the designated hazard prediction models produce similar results in a common, basic scenario; (2) Identify needs and priorities of operational users for NBC hazard information (3) Initiate a process to identify operational conditions under which model predictions begin to diverge; (4) Initiate efforts to exercise the models in a common scenario using high-resolution meteorological data provided the Naval Research Laboratory; (5) Determine the feasibility of conducting model predictions against field trial data.

STATEMENT OF WORK

This task will be conducted in two phases. Phase I consists of Tasks 1-5 below. If the results of Phase I indicate that a continuation of the effort would be productive, it is envisioned that this task order would be amended with further task descriptions and additional funding.

Phase I:

Task 1. Obtain the current standard released versions and documentation of the programs VLSTRACK, HPAC, and

D2PCw from the model proponents. Source code will not be obtained.

Task 2. Review field trial data from historical and current U.S. and international test programs. Identify those which might be applicable for testing model predictions under the widest ranges of weather, terrain, and distances sampled available. Model proponents may be consulted to provide the names of relevant tests illustrative of their model's performance. Any data obtained must come directly from the organization conducting the test, if the latter is not also the model proponent. Predictions or input data sets will not be obtained from model proponents.

Task 3. Identify and meet with operational users to characterize user needs and priorities for NBC hazard information at the various levels of command. Relate the type and quantity of information available to the operational users to the input and output space of the hazard prediction models. Effort on this task should not be permitted to delay completion of the other Phase I tasks.

Task 4. Develop a basic scenario in a regime common to the models. Exercise each model in this base scenario, using input parameters that are as identical as possible between models. Compare outputs using a common set of measures. Initiate a process of varying key parameters to identify operational conditions under which model predictions begin to diverge. Evaluate the feasibility of expanding this process to relate differences in model performance to the needs and levels of input data available to the various operational users. Initiate efforts to exercise HPAC and VLSTRACK in a common scenario using a 48-hour continuous high-resolution (3 kilometer) COAMPS meteorological data set supplied by the Naval Research Laboratory (NRL). Compare outputs between models and against a synthetic plume estimate supplied by NRL.

Task 5. Present an annotated briefing report to the sponsor, summarizing the results of Tasks 1-4 and identifying those cases (if any) where a model was unable to be competently exercised.

Phase II: TBD

APPENDIX E
ACRONYMS

ACRONYMS

A	Area
ABD	Airborne Division
ACOM	Atlantic Command
AFB	Air Force Base
AGL	Above Ground Level
AMD	Area of the Mean Dosage
ANATEX	Across North America Tracer Experiment
ANBACIS	Automated Nuclear, Biological, and Chemical Information System
approx.	approximate
ARTY	Artillery
ATP	Allied Tactical Publication
ATSD(NCB/CBM)	Assistant to the Secretary of Defense (Nuclear, Chemical, and Biological) (Chemical Biological Matters)
ASCOT	Atmospheric Studies in Complex Terrain
Batt.	Battery
Bio	Biological
BWA	Biological Warfare Agent A
BWB	Biological Warfare Agent B
BWC	Biological Warfare Agent C
CB	Chemical/Biological
CD	Compact Disc
CENTCOM	Central Command
CIA	Central Intelligence Agency
CINC	Commander-in-Chief
COAMPS	Coupled Ocean/Atmosphere Mesoscale Prediction
D2PCw	Downwind Chemical Hazard
DATSD (CP/CBD)	Deputy Assistant to the Secretary of Defense for Counter-Proliferation and Chemical/Biological Defense
def	default
deg	degrees
DIA	Defense Intelligence Agency
DoD	Department of Defense
DSWA	Defense Special Weapons Agency
DTRA	Defense Threat Reduction Agency
DUSA (OR)	Deputy Under Secretary of the Army for Operations Research
E	East
ECtX	Effective Concentration (by inhalation for this document)

	for X percent of the exposed population
ERDEC	Edgewood Research, Development and Engineering Center
ETEX	European Tracer Experiment
EUCOM	European Command
EUSA	Eighth United States Army
GB	Sarin
GD	Soman
GMT	Greenwich Mean Time
HD	mustard gas
hgt	height
HPAC	Hazard Prediction and Assessment Capability
hr	Hour
ICtX	Incapacitation Concentration (by inhalation in this document) for X percent of the exposed population
IDA	Institute for Defense Analyses
Inf	Infantry
JTF	Joint Test Force
Kg	Kilogram
Km	Kilometer
Kph	Kilometers per hour
L	Local time or Length
LANTFLT	Atlantic Fleet
LAT	Latitude
LCtX	Lethal Concentration (by inhalation in this document) for X percent of the exposed population
LDX	Lethal Dosage via Skin Contact (of the liquid for this document) for X percent of the exposed population
Loc	Local time
LON	Longitude
LR Msl (sm sub)	Long-Range Missile with Small Submunitions
LROD	Long-Range Over-water Diffusion
LSV	Large Scale Variability
m	meter
MCS	Maneuver Control System
MET	Meteorology
mg	milligram
µg	microgram
min	minute
mm	millimeter
MMD	Mass Median Droplet Diameter
N	North
na	not available
NATO	North Atlantic Treaty Organization
NBC	Nuclear, Biological, and Chemical

NOAA	National Oceanic and Atmospheric Administration
Nom	Nominal
NRL	Naval Research Laboratory
NSWC	Naval Surface Warfare Center
NUSSE4	Non-Uniform Simple Surface Evaporation
OLAD	Over-Land Atmospheric Diffusion
PACOM	Pacific Command
PC	Personal Computer
PGT	Pasquill-Gifford-Turner
PS	Pasquill Stability
R^2	Coefficient of Correlation
R and D	Research and Development
rds	rounds
s	second
SCIPUFF	Second Order Closure Integrated Puff
SF_6	Sulfur Hexafluoride
SOCOM	Special Operations Command
STRATCOM	Strategic Command
SWIFT	Stationary Wind Fit and Turbulence
T_{avg}	Conditional Averaging
T&D	Transport and Dispersion
TVX	Thickened VX
USAF	United States Air Force
USASOC	United States Army Special Operations Command
USFK	United States Forces Korea
UTC	Universal Time Coordinate
VLST	VLSTRACK
VLSTRACK	Vapor, Liquid, and Solid, Tracking
VX	Nerve Agent
W	Width or West
Z	Zulu time

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13. ABSTRACT (*Maximum 200 words*)
This report provides a limited operational assessment of the DoD standard NBC hazard prediction models, focusing on the VLSTRACK and HPAC models. The motivation for this effort was a concern about variance in hazard predictions produced by operational users. The study team conducted a survey of users at the CINCs and many of the major commands. There was little evidence of standardization or institutionalization of hazard prediction in general, or the use of models such as HPAC or VLSTRACK in particular. There were significant differences in focus, opportunities for model use, and skills at the various levels of command that are likely to have a considerable impact on the employment of the models. In comparing the models, even in simple scenarios, the models sometimes produced very different predictions. In several cases, there were significant differences in source term and toxicological assumptions. Accounting for these differences led to outputs that were more similar in some, but not all, cases. A significant portion of the variation appears to be due to fundamental differences in the modeling of transport and dispersion.

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